HOW TO OBSERVE.

GEOLOGY.

BY

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WITH AN HUNDRED AND THIRTY-EIGHT WOOD-CUTS.

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ADVERTISEMENT.

"Half a word fixed upon, or near the spot, is worth a cart-load of recollection."—GRAY.

SIR JOHN HERSCHEL, in his Discourse on the study of Natural Philosophy, remarks that " to make a perfect observer in any science, an extensive acquaintance is requisite not only with the particular science to which the observations relate, but also with every branch of knowledge which may enable him to appreciate the effects of extraneous and disturbing causes. Yet," he continues, " there is scarcely any well-informed person who, if he has but the will, has not also the power to add something essential to the general stock of knowledge, if he will only observe regularly and methodically some particular class of facts, which may most excite his attention, or which his situation may best enable him to study with effect. To instance one or two subjects which *can* only be effectually improved by the united observations of great numbers widely dispersed :—Meteorology, one of the most complicated but important branches of science,

is at the same time one in which any person who will attend to plain rules, and bestow the necessary degree of attention, may do effectual service. What benefits has not geology reaped from the activity of industrious individuals, who, setting aside all theoretical views, have been content to exercise the useful and highly en-tertaining task of collecting specimens from the coun-tries which they visit? In short, there is no branch of science whatever, in which at least, if useful and sensible queries were distinctly proposed, an immense mass of valuable information might not be collected from those who, in their various lines of life at home or abroad, stationary or in travel, would gladly avail themselves of opportunities of being useful."

These remarks, which gave rise to the idea of a work to be entitled " How to Observe," afford a sufficient indication of its object.

As yet, little has been done towards furnishing de-tailed instructions to observers. The chief exception to this remark which occurs to us is supplied in the directions contained in Mr. Babbage's admirable work on the Economy of Manufactures. The advantages and pleasures to be derived from accurate observation have indeed been often pointed out; and nowhere have they been better enforced than in the admirable tale of " *Eyes and no Eyes* " in " *Evenings at Home*." Per-haps, however, the best mode of exciting the love of observation is, by teaching " How to Observe." With this end it was originally intended to produce, in one or two volumes, a series of hints for travellers and students, calling their attention to the points neces-sary for inquiry or observation in the different branches

of Geology, Natural History, Agriculture, the Fine
Arts, General Statistics, and Social Manners.   On
consideration, however, it was determined somewhat to
extend the plan, and to separate the great divisions of
the field of observation, so that those whose tastes led
them to one particular branch of inquiry might not
be encumbered with other parts in which they do not
feel an equal interest.   Thus, the present Volume on
Geology is complete in itself, although contained in the
general plan of the series.

   It is hoped, that whilst " How to Observe" will afford
assistance to the scientific traveller and student, it will
also be the means of inducing others to collect infor-
mation on all or some of the heads noticed.   Thus
the listless idler may be changed into an inquiring
and useful observer, and may acquire the power of con-
verting a dull and dreary road into a district teeming
with interest and pleasure.   To acquire this power,
it is not necessary that the observer should be pro-
foundly skilled in all the subjects that come under his
observation.   He may soon acquire sufficient know-
ledge to appreciate what he sees, and to express what
he feels.   The charm that such habits of observation
bestow upon the descriptions of the commonest things
is evident in those works in which the observer expresses
what he has seen with his own eyes simply and correctly.
What reader is there who has not risen with delight
from every fresh perusal of White's Natural History of
Selborne, a work at once showing the importance of
accurate and detailed observation, and the small quan-
tity of scientific knowledge requisite to produce that
which is both valuable and interesting.   On the other

hand, the writings of St. Pierre, abounding with elo-
quence and picturesque descriptions, are now nearly
forgotten, because they are wanting in that accuracy
and minute observation which alone can command a
lasting interest.

<div align="right">H. B. K.</div>

London, June 1st, 1835.

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HOW TO OBSERVE.

GEOLOGY.

PART I.

GEOLOGICAL observations may be conveniently class-
ed under two heads : first, those which bear immediately
on Geology viewed strictly as a science ; and secondly,
those which show its connexion with the various ne-
cessities and comforts of mankind, such as agriculture,
mining, building, &c.   We shall, in the first place,
endeavour to point out the manner in which those who
desire to advance the science of Geology may effectively
do so, though they may as yet be little acquainted with
it, and then proceed to consider the second class of
observations, which have, in general, been too much
neglected.

   There are probably few so little observant of natu-
ral objects as not to have remarked that the appear-
ances of countries differed materially according to their
soils, and that these again were connected with the
kinds of mineral substances found beneath them, such
as sands, clays, and various kinds of solid rock.   It
must also have been observed, while travelling in par-
ticular directions over lines of country not far removed
from each other, that a succession of similar kinds of soil

B

or rock frequently occurred ; so that if the points where
the various changes took place in the different roads
were marked upon a map, and that lines were drawn
from point to point where the same changes of soil or
rock were observed, certain portions of country would
be marked off in which the same kind of soil or rock
would prevail.

Fig. 1.
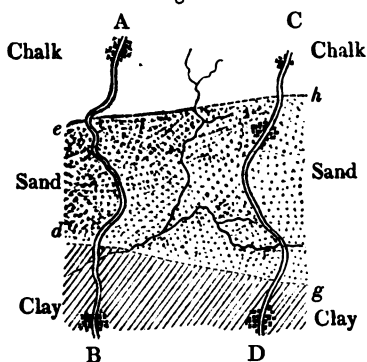
Let us suppose that a traveller takes his course from
B to A by the road B A, and that the town or village B
stands upon clay which he finds is continued to *d*,
where sand forms the soil and rock of the country.
The traveller would probably class the country he has
passed over among the clay districts.   Let us further
suppose that the same observer, in the prosecution of
his journey, finds the sandy country to end at *e*, after
which chalk forms the rock to the termination of his
journey at A.   The traveller would scarcely fail to
consider the district he has traversed as composed, in
succession, of clay, sands, and chalk ; but he would still

be unacquainted with the direction taken by any of these kinds of country.

Let us now consider that the same traveller had occasion to pass over another road, D C, to a certain extent parallel to the former, B A, but distant from it a few miles, and that he found a clay at D, similar to that on which B is situated. Our observer would now most probably conclude that the clayey country of B extended to D. If in the progress of his journey the traveller quits the clay at *g*, and finds the same kind of sandy rock and soil that he had previously observed at *d* on the road B A, and further if at *h* he enters upon the same kind of chalky country that he found at *e* on the other road, he might be induced to draw lines on his map from *d* to *g*, and from *e* to *h*, which would thus divide the portion of country included between the roads B A and D C into three parts—one clayey, another sandy, and the third chalky.

Having advanced thus far in what may be considered a rude attempt at a geological map, the observer may probably infer that there is something like a succession of mineral substances in this part of the country, and be induced to travel over other portions of the district, to the right and left of those he has thus noticed, to see if the 'same kind of succession continued in those directions; and finding this, he might conclude that soils, or rather the rocks or mineral substances whence they are principally derived, are not confusedly mixed up with each other, but that they occur in a certain order of succession, viewing the subject more generally. Having arrived at this conclusion, his next step would probably be to ascertain whether these mineral sub-

stances or rocks rested upon each other ; and if so, their
relative order of superposition. We will suppose, for
the sake of illustration, that he finds the clay, as seen
in the annexed section,* Fig. 2, to rest upon the

L   Fig. 2.

Clay

         Sands   Chalk

sands, and these again on the chalk. Having clearly
ascertained this fact in several places, he could not
be otherwise than convinced that, in the district ex-
amined, these mineral substances or rocks succeeded
each other in the order represented in the section,
which may at the same time afford a rough idea of
the geological structure of the country near London,
the clay being termed the ' London clay,' because the
metropolis (L) stands upon it, beneath which are certain
sands interstratified with clays (named plastic because
used in pottery) that in their turn repose upon chalk,
which rises in hills at various distances to the S., W.,
and N. of the metropolis.

* A geological section is considered to be vertical, unless other-
wise stated. Like other sections, it is supposed to be some mate-
rial thing divided ; so that one part being removed, the structure
of the other part is well seen. Thus, when we divide an orange or
an apple, we make a section which exposes their interior structure,
which is otherwise concealed. Some geological sections are
natural, such as those afforded by sea-cliffs ; some are artificial,
such as deep cuts for roads and other purposes ; while others are
ideal, like that in the text, being constructed from the knowledge
of various facts which render them either highly probable or
almost certain,—it, of course, being understood that all possible
care has been used in their construction.

Having, from these simple observations, ascertained that some rocks at least succeed each other in a certain order, an intelligent person would probably have his curiosity so far stimulated as to inquire whether other observers have remarked similar successions of rocks in other districts and countries.   Finding that the subject had long engaged the attention of several other persons, he would naturally be anxious to learn the conclusions they had deduced from their observations, as also 'how to observe' any facts he may chance to meet with, in order that he should obtain not only a general idea of existing knowledge on the subject, but also the power of employing his time to the best advantage by not sacrificing it in observing things of little or no importance.   It is our object to afford this general idea of the present state of geology, with directions to the traveller and student 'how to observe,' so that their labour may not be thrown away ; trusting also that some few who may peruse these pages and who have not hitherto attended to the subject, may be induced to observe and record facts that may advance the science, and which might otherwise be passed unnoticed.

The researches of Geologists have taught them that the rocks* which constitute the visible solid surface of our earth have either been deposited from water where, for the time, the substances of which they are composed

* The term 'rock' is applied by Geologists to all kinds of coherent mineral masses composing the solid crust of our globe, whether they be hard or not.   Thus various clays, marls, soft sandstones, and the like, are termed rocks, when they form portions of the series of mineral masses composing land.   Even incoherent sands are termed rocks when they constitute a component part of a series of beds or strata.

were either chemically or mechanically suspended, or
have once been in a liquid melted state from the action
of heat upon them. The former are termed aqueous, and
the latter igneous rocks, from the nature of their origin.
Rocks are also classed under the heads of 'stratified'
and 'unstratified;' terms considered synonymous with
'aqueous' and 'igneous.' There are objections to
these terms, as will be perceived in the sequel; but as
they do not outbalance their convenience in the pre-
sent state of geology, we shall employ those of 'strati-
fied' and 'unstratified,' as is now mostly commonly
done.

When rocks are divided into beds like the leaves of
a book, or several books or pieces of cloth piled upon
each other, they are said to be stratified. When an

Fig. 3.
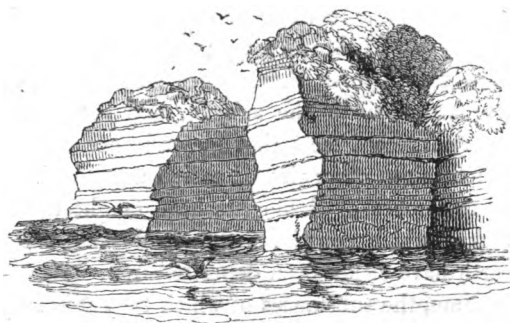
observer finds a series of beds resting upon each other
as represented in the cliffs, Fig. 3, he has before him a
rock or rocks said to be stratified. It is, however, by
no means necessary that the rocks should be divided
into beds as flat as the leaves of a book, or as pieces of
cloth laid upon each other, to entitle them to the term

stratified. Such beds as those represented in the annexed sketch (Fig. 4) would still be termed strati-

fied. When no traces of beds can be detected, and the rock merely forms a great mass of mineral matter, without other lines than those of cleavage, to be noticed hereafter, it is said to be unstratified. Such rocks have frequently the heavy lumpy character represented beneath (Fig. 5).
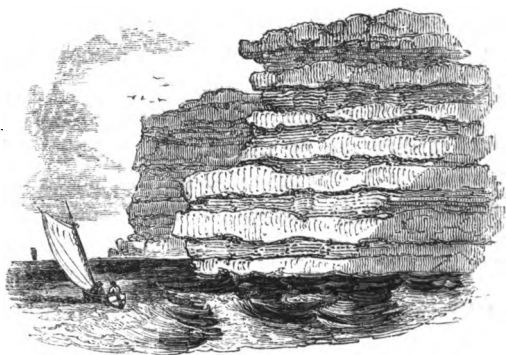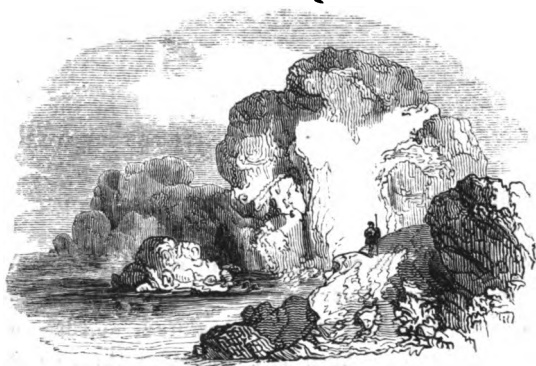
The stratified rocks are divided into two classes, the 'fossiliferous' and the 'non-fossiliferous;' the former containing the remains of animals and plants which have once existed, and whose exuviæ, found in various states of preservation and mineralization, are commonly termed fossils or organic remains, while the latter afford no traces of .such exuviæ. These terms are applied to the rocks in ·question as masses; for though the non-fossiliferous rocks are never found to contain organic remains, many beds among the fossiliferous are also without such exuviæ, and might therefore, as far as regarded themselves, be termed non-fossiliferous; but being associated as the bed c (Fig. 6) is with a, b, d,
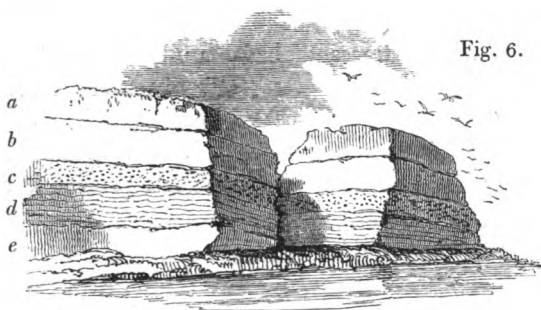
Fig. 6.

and e, organic remains being detected in the latter, while they are not found in the bed c, they are necessarily included among the fossiliferous class, the absence of fossils being accidental and due to particular circumstances.

The non-fossiliferous rocks are also known by the name of 'primary,' because they are the lowest stratified rocks with which we are acquainted, and hence are considered to have been first formed. Among them

we observe facts which render it necessary that we should, in the true spirit of philosophical inquiry, be extremely cautious in supposing that all beds of mineral matter, or stratified rocks, have been deposited from water. It is not our intention to enter into a discussion on this head, referring to the various treatises on geology for information on the subject ; but we mention it to guard the reader from a too ready acquiescence in the belief that all rocks divided into beds, or stratified, particularly among the non-fossiliferous class, are necessarily of aqueous origin.

The non-fossiliferous rocks are for the most part formed of a mixture of a few minerals, the most important of which are quartz, felspar (common and compact) hornblende, mica, schorl, garnet, chlorite, talc, and steatite. A great variety of others occasionally enter into their composition ; and one, carbonate of lime, sometimes constitutes whole associated rocks, most frequently in the form of statuary marble. It rarely happens that these rocks are not crystalline or subcrystalline. For the most part they form confused mixtures of two, three, or more of these minerals ; and are then known, according to the particular mixture, by different names,—such as *gneiss, mica slate, talcose slate, hornblende rocks*, &c. For particular descriptions of these rocks we must refer to treatises on geology ; recommending the reader, if unacquainted with the subject, to dedicate a short time in some good cabinet or museum to the study of the rocks in question, in company with a competent person, by which he will learn more in a few hours than in weeks spent in the mere perusal of descriptions. It may however be remarked, that, viewed chemically, the non-fossiliferous rocks constitute

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a mass of silicates, among which carbonates are very sparingly disseminated. The principal silicates are those of alumina, potash, soda, magnesia, and lime; and the carbonates, those of lime and magnesia. Silica is the chief ingredient, alumina the next important substance; and then follow potash, magnesia, and soda. Lime and fluoric acid are extensively disseminated in small quantities, and the oxides of iron and manganese are also common, the former greatly predominating.

Upon these repose the fossiliferous rocks; and in them we have evidence that animal and vegetable life existed on our planet before such rocks were formed, since their remains are detected in them. Among the members of the non-fossiliferous class it cannot be said that any particular order of superposition is observable; though, viewed in the mass, the particular mineral compounds named gneiss and mica slate may be said to prevail in its lowest parts. With the fossiliferous rocks, however, the case is different: among them we find a certain order of superposition which has never been found inverted; that is to say, if the order be that

Fig. 7.

of *a, b, c, d*, in the annexed section (Fig. 7), we never find *d* resting upon *a*, or *c* upon *b*, though we may find

Fig. 8.

a resting upon *d*, as above (Fig. 8), either from *b* and *c* never having been formed in that particular situation, or, having been so, they were swept away before the production of *a*, which would necessarily cause *a* to rest immediately upon *d*.

When we state that a given order of superposition reigns among the fossiliferous rocks, it must not be understood that particular mineral compounds are not repeated in the series; for in fact they are so repeated, various sandstones, clays, and limestones often differing slightly, if at all, from each other, following no more order as mineral substances than the non-fossiliferous rocks noticed above. By a given order of superposition among the fossiliferous rocks, we mean that certain masses of mineral substances, no matter what kind of mineral substances they may be, have been produced at distinct geological periods, one after the other; and that, as far as researches have yet extended in Europe, where they have been most studied, they contain, as masses, certain assemblages of organic remains not detected in the others. That is, if, for the sake of illustration, we suppose a series of fossiliferous

Fig. 9.

a b c d e f g h i k l m n o

rocks, *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, *i*, *k*, *l*, *m*, *n*, *o*, to rest upon one another as in the above diagram, (though it must not be supposed that such a number of fossiliferous rocks ever succeed each other in nature with such perfect regularity and parallelism,) each would contain

organic remains differing as a whole from those disco-
vered in the others, either above or beneath it ; though
a, e, g, m, may be sandstones ; *b, d, h, k, o,* shales or
clays ; and *c, f, i, l, n,* limestones.

The fossiliferous rocks have, for convenience, been
arranged in groups bearing various names, which in
general show the countries where each group has been
more particularly studied or developed.   As these
rocks are chiefly of mechanical origin, though many
are evidently precipitates from chemical solutions, it
cannot be expected that any great uniformity of mineral
structure should be observed over very extended areas,
far less that we should find the same mineral composi-
tion in rocks of equal age over the face of the globe :
—unless, indeed, we suppose equal circumstances to
obtain over the whole superficies of our planet at the
same times ; which would evidently be an absurdity,
when rocks of mechanical origin are concerned, or those
derived by aqueous abrasion from pre-existing rocks,
and which are deposits from water in which their com-
ponent parts have been mechanically suspended.   In
order, however, to enable the reader to become ac-
quainted with those mineralogical compositions which
have been considered characteristic of the fossiliferous
rocks within certain comparatively minor areas, we
have in the following table, exhibiting the order of
superposition and the subdivisions of the fossiliferous
groups, given a short notice of the mineral structure
of the rocks beneath the supracretaceous or tertiary
beds ; premising that such structures are merely cha-
racteristic of more or less limited areas, as we shall have
occasion still further to insist upon.

List of the Fossiliferous Rocks of part of Western Europe, in the descending Order.

GROUP.	SUBDIVISIONS.	MINERAL STRUCTURE.
1. Modern.		Detritus of various kinds deposited from water in which it was mechanically suspended; modern calcareous, siliceous, and other chemical deposits from water; coral islands, reefs, &c.
2. Supracretaceous. *Tertiary* rocks of the improved Wernerian classification ;) *superior* rocks of Conybeare.	Divided by Lyell, who retains the name *tertiary* for this group, into four subgroups; *viz.* newer pliocene, older pliocene, miocene, and eocene.	Detritus of various kinds deposited from water; calcareous, siliceous, and other deposits from chemical solutions, &c.
3. Cretaceous. (Highest of the *secondary* rocks of the improved Wernerian classification; highest of the *supermedial* rocks of Conybeare.)	*a.* Chalk.	The well-known calcareous substance so named, mixed with flints, particularly in its upper part.
	b. Upper green sand.	An arenaceous rock, for the most part very calcareous, in which green grains of silicate of iron are abundant.
	c. Gault.	An argillaceous deposit of a bluish grey colour, containing much calcareous matter.
	d. Lower green sand.	Sands and sandstones, principally of ferruginous or green colours, the latter prevailing in the lower portions.
4. Oolitic.	*a.* Portland stone.	Beds of an oolitic limestone, or roestone, associated with compact limestone beds, flint and chert.

GROUP.	SUBDIVISIONS.	MINERAL STRUCTURE.
Oolitic (*conti-nued.*)	*b.* Portland, or Kimmeridge sands.	Calcareo-siliceous sands and con-cretions.
	c. Kimmeridge clay.	An argillo-calcareous deposit, sometimes carbonaceous.
	d. Upper calca-reous grit.	An arenaceous deposit.
	e. Coral rag.	So named from an abundance of fossil corals generally detected in it. The oolitic limestones as-sociated with it are sometimes of so large a grain as to be termed *pisolite*.
	f. Lower calca-reous grit.	An arenaceous rock.
	g. Oxford clay.	A grey argillo-calcareous deposit, in the lower part of which a calcareous sandstone, named Kelloway rock, is often deve-loped.
	h. Compound great oolite : including, in the descending order, 1. Corn-brash, 2. Forest marble, 3. Brad-ford clay, 4. Great or Bath oolite.	A series of calcareous rocks, com-pact, oolitic, and friable; some-times associated with clays or marls. A rock, remarkable for its organic contents, and named Stonesfield slate, sometimes forms the base of the great oolite.
	i. Fuller's earth's.	An argillaceous deposit, so named because fuller's earth is obtained from it in some localities.
	k. Inferior oolite.	The upper part formed of calca-reous beds in which grains and small nodules of hydrate of iron are abundant, while the lower part principally consists of cal-careo-siliceous sands and con-cretions.

GROUP.	SUBDIVISIONS.	MINERAL STRUCTURE.
Oolitic (*conti-nued.*)	*l.* Lias.	An argillo-calcareous deposit, in which beds of argillaceous lime-stones are frequently developed, particularly in the lower portions.
5. Red sand-stone.	*a.* Variegated or red marl.	Marls of various tints of red, blue, grey, green, and white ; the former greatly predominating. Gypsum is frequently found in them, and rock salt is occa-sionally detected.
	b. Muschelkalk.	Limestone beds of variable tex-ture, but most frequently grey and compact. This rock is oc-casionally dolomitic.
	c. Red or varie-gated sandstone.	An arenaceous deposit, principally argillaceous and siliceous, of various tints of green, white, blue, and red ; the latter greatly predominating. Occasionally contains masses of gypsum and rock salt.
	d. Zechstein, or magnesian lime-stone.	Limestone beds, in which carbo-nate of magnesia is disseminated in variable quantities, so that the rock sometimes becomes the crystalline compound of the carbonates of magnesia and lime named *dolomite*. The whole rests upon a marl slate, named *kupferschiefer,* because it contains copper in Germany.
	e. Rothliegendes.	A series of red sandstones and conglomerates, occasionally in-termingled with red marls or clays. In some situations the sandstones prevail ; in the others, the conglomerates ; the latter ge-nerally occupying the lower parts.

| GROUP.	SUBDIVISIONS.	MINERAL STRUCTURE.
6. Carboniferous. (The authors who employ the improved Wernerian classification vary in this part of the series. Some commence the *transition* rocks with *a*, others with *b*, and others again with *c*.) *Medial* rocks of Conybeare.	*a.* Coal measures.	A variety of shales, sandstones, and occasionally conglomerates ; among which coal-beds, differing considerably in thickness, are associated.
	b. Carboniferous limestone.	Compact limestones, for the most part of a grey tint, often sufficiently hard to be employed as marble.
	c. Old red sandstone.	A variety of sandstones, chiefly red, among which conglomerates sometimes occur, as also calcareous portions, named *cornstones.*
7. Grauwacke. . (*Transition* rocks of the Wernerian classification ;— *sub-medial* rocks of Conybeare.)	. . .	A considerable accumulation of arenaceous rocks, among which conglomerates occasionally occur. It is chiefly composed of argillaceous and siliceous matter, forming slates and sandstones. Limestones in exceedingly subordinate quantities occur in various parts of the series, and beds of anthracite are sometimes detected in it. Its tints are principally grey and brown, but red is here and there found in all parts of this series. The lower portions appear to graduate, principally by an increase of associated crystalline strata, into the non-fossiliferous rocks.

We have said that the mineral structures of the groups and their subdivisions, above noticed, could only be considered characteristic of minor areas ; and we may cite in illustration, that while the compound great oolite of Somerset and Wilts is formed principally of calcareous matter enveloping a great abundance

of marine organic remains, its equivalent in Yorkshire is chiefly composed of arenaceous and shale beds with associated coal, the remains of terrestrial plants being exceedingly abundant, while marine exuviæ and the calcareous strata containing them are of a very subordinate character. Again, the old red sandstone, which in Herefordshire is an important arenaceous rock, is in the North of England represented by a conglomerate, sometimes of inconsiderable thickness. The carboniferous limestone also of Southern England, in which coal does not occur and limestone so greatly prevails, is in Northern England represented by sandstones, shales, and coal-beds, the limestone becoming to a certain degree subordinate. On the other hand, the mineralogical character of some groups, or their subdivisions, is constant, or nearly so, over considerable areas. We may cite as illustrative of this fact the well-known white chalk, which preserves its mineral character from the borders of the Sea of Azof, through part of Russia, Poland, Sweden, the northern parts of Germany, the British Islands, and in a large portion of France. Certain argillaceous portions of the oolitic group cover extensive areas, and the general mineral character of the grauwacke is remarkably similar in Europe and North America.

The reader may here demand the utility of observing the mineralogical characters of these rocks at all, since they are thus changeable. A little reflection will, however, show him that to observe these changes is particularly important, since they prove that equal circumstances have not obtained throughout the area occupied by any given group of rocks, or its subdivisions, during

the period of its or their formation, and that by noting
the kind of changes which take place he may approxi-
mate towards a knowledge of the circumstances which
have produced them.

Fig. 10.
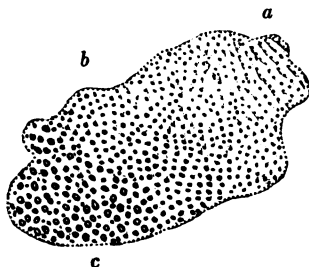
Let *a*, *b*, *c*, (Fig. 10) represent an area occupied by
a mechanical rock, that is, one formed of the detritus
of pre-existing rocks,—an area which for the sake of il-
lustration we may estimate equal to a thousand square
miles,—a fine sandstone approaching to clay being found
at *a*, coarser grained sandstone at *b*, while conglomerate
is discovered at *c*, the various parts shading into each
other, so that no doubt can exist that the whole is geo-
logically contemporaneous, that is, formed at the same
geological epoch. It is clear that exactly the same
circumstances have not obtained over the whole area
during the deposition of the rock. As, in all probabi-
lity, moving water has carried the component parts of
the rock into the respective situations they now occupy,
we might infer that the velocity of the transporting
water had varied in the different situations; for it is
clear that a velocity merely sufficient, all other things

being equal, to carry the silt at a would be insufficient to move the coarser sand at b, while the larger fragments and pebbles at c could not be transported by the same force which would merely move the particles of sand at b. We might in fact infer that there was a greater intensity of moving power at c than at a, gradually decreasing from c to a; and consequently, if the same body of moving water has carried the parts of the rock to their present respective situations, that the velocity of such moving water decreased from c to a. By examining mere sandy clay, or even sand, the evidence as to the quarter whence the detritus was derived is not always satisfactory : with pebbles or fragments of rocks the case is, however, for the most part different ; and we thus frequently obtain direct information as to the quarter whence they have been derived, such pebbles or fragments being portions of older rocks often visible in the district or country where the conglomerate exists. We will not here enter into the various ways in which moving water may distribute detritus, since the above remarks are merely intended to show that observations respecting the variations in structure of mechanical rocks possess considerable interest, and are highly important as respects theoretical geology.

When we find a rock crystalline and without organic remains in one part of its course, while other parts are not crystalline, perhaps even arenaceous, and replete with animal and vegetable exuviæ, it is clear that some circumstances have obtained in one part of the area not common to the whole ; and if we desire to rise from a

view of the rocks themselves to the probable causes
which have produced them, it is also evident that it is
important to observe these differences with great care,
since it is only by caution and duly weighing the evi-
dence before us in all its bearings that we can approxi-
mate towards the truth.

In the above diagram (Fig. 10) we have supposed;
for more easy illustration, that the rock was horizontal
and uncovered by others: more frequently, however,
rocks are not horizontal, and are covered by others over
the larger portion of the areas which, we infer, are oc-
cupied by them. They are often tilted up, as in the
vertical section beneath (Fig. 11), where we have sup-

Fig. 11.
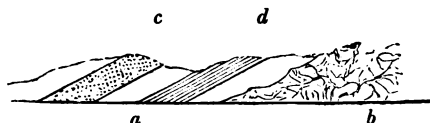
posed the stratified rock *a* to have been thrust up at
one end by the protrusion of the igneous rock *b;* or
they may have taken an inclination even equal to 30°
or 40° when deposited.*   In either of these cases vari-
ations (if there be any) in the structure of such beds
as *c* or *d*, or of the general assemblage of beds com-
posing the rock, can only be observed where the edges
of the strata cut the surface of the country, or in natu-
ral or artificial vertical sections, such as ravines, quar-
ries, &c.   The lines in which such tilted or inclined
beds cut the horizontal plane are termed those of *strike*

* See Researches in Theoretical Geology, by H. T. De la
Beche, p. 50.

or *direction;* and by carefully observing the changes
which take place in certain beds, or in the rocks gene-
rally of which they constitute the component parts,
much valuable information may be obtained.   To illus-
trate this, let us suppose that the lines *a b* and *c d*

Fig. 12.
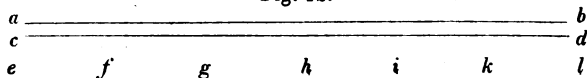
represent the strike or direction of a highly inclined
portion of the grauwacke of Southern Devon, where
such changes are very common, and that the distance
between the lines is about a mile.   We may have an
argillaceous slate at *e*, which passes into an arenaceous
grauwacke at *f*, becoming a quartz rock at *g*, whence
it again shades off to an arenaceous grauwacke at *h*, be-
coming more argillaceous at *i*, an argillaceous slate at
k, and almost a roofing slate at *l*.   From thus ob-
serving the various mineral conditions of the fossilife-
rous rocks, and noting the size of the respective areas in
which the same mineral structure prevails, we obtain
the comparative value of each condition, and conse-
quently of the probable cause which may have pro-
duced it.

Although we should thus obtain information as to
the variable forces of moving water by which abraded
portions of pre-existing rocks have been deposited in
new situations, and frequently of the quarters whence
such detritus has been derived, as also of the relative
amount of chemical products mixed with the mecha-
nical rocks of the same geological epoch; we should

not know that any other than the existing species of
animals and plants had ever lived on the surface of our
planet, or that there had been successive creations of
animals and plants, called into existence and destroyed
as new conditions arose, either over the earth's surface,
or in areas of different magnitudes.   The fossiliferous
rocks afford us, by their organic contents, not only this,
but also much collateral information of the highest in-
terest, as well botanical and zoological, as geological.
To the botanist and zoologist naturally belongs that
careful investigation of organic remains which enables
them to determine their true or highly probable place
among those known created things which either have
possessed or now possess life; while the geologist
masses the information thus derived, and combines it
with the probable causes that may have produced those
conditions under which inorganic matter is presented to
his attention on the surface of the earth.

   For information respecting the various organic re-
mains detected in the fossiliferous rocks, we must refer
to those works which profess to give lists of such as
have been hitherto described.*   These lists are far
more full than those unacquainted with the subject
might suspect, and exhibit the great practical benefit of
the division of labour ; for though many of these exuviæ
have been brought to light by those who may be strictly
termed geologists, a large proportion have been col-

   * For the organic remains found in the supracretaceous group
(or tertiary rocks), consult Lyell's Principles of Geology, vol. iii.
1st edition ; and for those from the cretaceous to the grauwacke
groups inclusive, De la Beche's Geological Manual, 3rd edition.

lected by persons whose acquaintance with geology, properly so called, has been limited.

It was once assumed that given assemblages of animal and vegetable exuviæ, discovered in particular rocks, would be found to characterise the mineral deposits of a given geological epoch, if not over the whole face of the globe, at least over very large portions of it. The distribution of animal and vegetable life over the surface of the earth being now so various, that no naturalist expects to find precisely the same animals and plants in localities far distant from each other, even when such localities are perfectly similar with respect to climate and other circumstances; it follows, that the supposition of given organic remains being always detected in rocks of the same geological epoch wherever such rocks may be found, is utterly at variance with the present distribution of animal and vegetable life over our planet.

Such hasty generalizations are common in the early history of most sciences, and can only be considered effectively mischievous when there is a determination to uphold them in spite of direct evidence of their unsoundness. It is more generally considered in the present day, that given organic remains are spread over larger areas, in contemporaneous rocks, in proportion to the geological antiquity of such rocks : that is, we should expect to find greater uniformity in the animal and vegetable exuviæ entombed in the grauwacke of distant localities than in the supracretaceous rocks of equally distant situations. Now it is remarkable that, as far as investigations have yet gone, there is much to support this hypothesis ; but we must be careful in not

assuming it to be absolutely true until observations be greatly more multiplied than they are at present. If, however, we suppose it true, it can only be so to a certain extent; since we can scarcely imagine such complete uniformity of conditions over the globe, un- modified by local causes, as to afford exactly the same results everywhere. Moreover, we have direct evidence to adduce that the organic contents even of the more ancient rocks vary over minor areas. If the annexed

Fig. 13.

sketch (Fig. 13) represent an area of eight or ten thousand square miles occupied by some given rock, of the continuity of which, though frequently covered by more modern deposits, there exists no doubt, it rarely happens that the organic contents of such a rock would be found precisely the same at a, b, and c, re- spectively. It might so happen that marine exuviæ were alone detected at a, while remains indicative gene- rally of the proximity of land were discovered at b, and little else than terrestrial plants were found at c. Independently of this change in the organic character of the deposit, we should probably also obtain a differ- ence in its mineralogical character; the rock being per-

haps a limestone or highly calcareous at *a*, more argil-
laceous or clayey at *b*, while sandstones, shales, and
even coal may constitute the mass at *c*.

The reader will have gathered from the preceding
observations, that a combined view of the organic and mi-
neralogical characters of the fossiliferous rocks is highly
important, since we thence approximate towards a know-
ledge of the various causes which have attended their
production. The question also of whether the ancient
fossiliferous rocks are more constant in their organic
characters over considerable areas than the modern, is
also one of high geological interest, since, however little
they may differ mineralogically from each other viewed
in the mass, it is clear, if there be this difference in
their organic character, there must have been some mo-
difying circumstances at one epoch different from those
at the other. It can only be by multiplied observa-
tions that this can be decided; and the power of con-
tributing to solve this, as well as many other geological
problems, is alike open to him whom these pages may
induce to observe, as to those who have passed years
in the study, and who, as geological pioneers, have
smoothed many a rugged path for those who follow
them.

When fossiliferous rocks rest *conformably* upon each
other, (that is, when, as in the annexed section, a series of

Fig. 14.
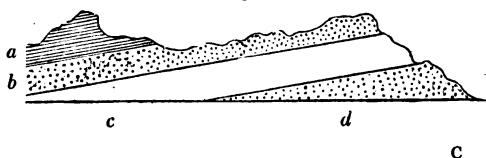
deposits rests upon an other in a manner which will not permit us to suppose that the lowest, *d*, has been heaved up, or otherwise disturbed, before the next above it, *c*, was formed, and so on with *b* and *a* in succession,) it is inferred that, in the situation where these rocks have been deposited, the organic exuviæ found in them are the remains of either animals or plants, as the case may be, which have succeeded each other in the same place in the order of the rocks themselves.   It is not to be inferred, as has sometimes been done, that similar animals or plants succeeded each other over the whole surface of the globe; for, in the extension of a series of deposits such as that represented above (Fig. 14), in other directions other deposits may be discovered between the rocks of which it is composed, and yet, in the situation first observed, the rocks may rest as tabular masses conformably upon each other.   Let us suppose that *a* and *b* (Fig. 15) represent the same rocks as *a* and *b*, Fig. 14, then *m* might be included between them at *o*, while at *p* they should appear strictly conformable, the rock *m* having *fined off*, as it is termed, in the horizontal distance between *o* and *p* ;

Fig. 15.

that is, its vertical thickness has decreased by degrees, so that the horizontal extension of *m* would not be so great in this situation as that of *a* and *b*.   It, however, by no means follows that *m* does not cover a greater

area altogether, for it may readily do so, *a* and *b* fining
off between other rocks in other directions.

When fossiliferous rocks rest *unconformably* upon
each other,—that is, when, as in the annexed section
(Fig. 16), a rock, *a*, rests upon the upturned edges of

Fig. 16.
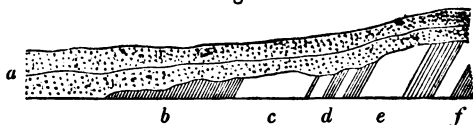
the beds *b*, *c*, *d*, *e*, *f*,—we cannot infer that the animals
and plants whose exuviæ may be detected in *a* suc-
ceeded those whose remains are discovered in *b*, since
many rocks may have once existed above *b*, which
have been carried away by *denudation*, as it is termed ;
that is, removed by the abrading power of moving
water before *a* was formed : and if the angle be so
considerable as that represented above (Fig. 16), we
should infer that the rocks *b*, *c*, *d*, *e*, *f*, were tilted up
by violence before *a* was deposited.   There is also
another kind of superposition which may be termed
irregular, even when the beds of two rocks in contact
may, as masses, rest conformably on each other.   If we
find, as in the annexed section (Fig. 17), that the

Fig. 17.
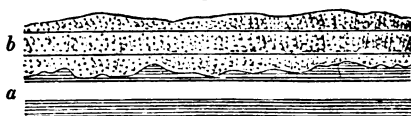
upper surface of a fossiliferous rock, *a*, has been water-
worn before another fossiliferous rock, *b*, was deposited

c 2

upon it, we have no evidence to show that the animals and plants existing when *a* was formed were succeeded by those whose remains are detected in *b*; other intervening deposits may have been thrown down, and subsequently swept away, after the production of *a* and before the formation of *b*.

As this is not intended for an essay on the present state of geology, we shall now briefly notice the igneous rocks, and then proceed to our more immediate object, 'how to observe.' Those rocks are termed igneous which we consider to have once been in a fluid state from the action of heat upon them, and in that state to have overflowed, to have been injected among, or to have been propelled through, other rocks.

In volcanos we have direct evidence that liquid melted rock may be heaved out of the earth by forces acting beneath, and in that state flow over those channels which offer it the least resistance, thus forming the well-known *lava currents*. When also, from a change in the volcanic vent, great natural sections are afforded of a former crater, it is sometimes found that the melted rock has risen among the layers of ashes and cinders of former eruptions, cracks having been produced in the mass of such ashes and cinders, into which the fluid melted rock has risen.

It is from similar facts being observable in the mode of occurrence of other rocks, known by the names of granite, greenstone, porphyry, &c., that we infer that they also have had an igneous origin, though not always under the same conditions as those observable in a modern volcano. When, for instance, a mass of granite, *a*, (Fig. 18,) sends out veins, *c c*, into a deci-

Fig. 18.
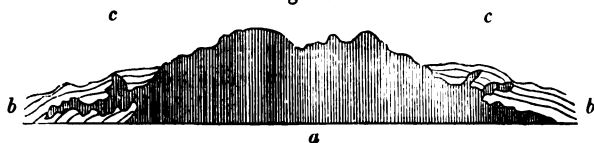
dedly stratified rock, *b b*, cutting the strata in various
directions, the veins even including fragments of the
rock, *b b*, we infer that the granite in question was once
in a fluid melted state, was protruded through *b b* by
forces acting beneath, and that a portion of the melted
rock was forced into cracks at *c c*, thus forming the
veins in the stratified rock *b b*, the beds of which were
also upheaved at the same time. The inferences would
be the same whether the protruded rock be granite,
greenstone, porphyry, basalt, or others.

When, as in the annexed view (Fig. 19), a long
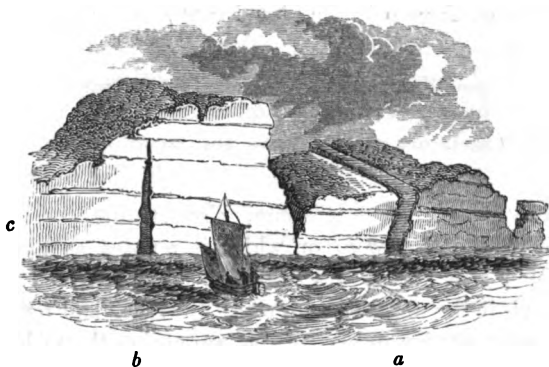
narrow mass of rock divides another, in the manner *a*
does *c*, and this narrow mass of rock is composed of
substances similar to those which constitute greenstone,

porphyry, or the like, we infer that the beds of the rock *c* were once continuous, that they have been subsequently broken, and that into the fractures liquid melted rock arose, filling the cavity formed by the crack.   To these intruded masses of rock, consolidated as we now find them, the name of *dyke* is given, and they are known as greenstone, porphyry, basaltic, or other dykes, according to the kind of rock of which they are composed.   Even when these masses of intruded rock do not rise to the surface of the land, and are only known to exist by natural or artificial sections, as at *b*, Fig. 19, they are still termed dykes.

We have sometimes good evidence to show that certain igneous rocks have, after traversing pre-existing beds, spread like a sheet over them, leaving masses, sometimes nearly tabular, at others more domed-shaped, above the pre-existing beds.   When, as in the annexed section (Fig. 20), we find a superior mass of any given
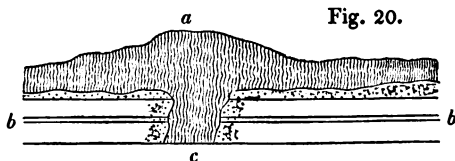
Fig. 20.

rock, *a*, such as greenstone, also cutting, as at *c*, through the rock *b b*, on which it reposes as a mass, we infer that a rent was made at *c*, in *b b*, and that through it the melted rock flowed upwards, and formed the upper portion or cap, *a*.   If, supposing the rock *b b* a common fossiliferous limestone, we find those portions which are in contact with or near the greenstone to be crystalline, or *b b* being sandstone or shale greatly indurated, with even perhaps a tendency to

new arrangements in their component particles, we fur-
ther infer that such alteration has been caused by the
presence of the greenstone when liquid or intensely
heated. Deposits which have suffered this change, —
more particularly when such effects are observable on
the large scale, and the distance from the once heated
mass is measured by hundreds of feet and not by inches,
—are termed *altered rocks.*

While the melted rock seems in some instances
merely to have risen quietly in a crack or fissure,
like any other liquid, to a level at which it can be
supported by any proper force acting upon it; at
others, as in Fig. 21, we find the two rocks so
situated relatively to each other, that we can scarcely
refuse to consider that the rise of the igneous rock

Fig. 21.
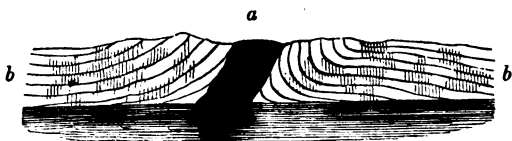
has been accompanied by force. If *a* (Fig. 21) be
the intruded igneous rock, and *b b* a stratified de-
posit, then the beds near *a* being turned up on both
sides of the dyke, we should infer that the substance of
which *a* is composed had been thrown up with sufficient
force to turn up the edges of the stratified rock, *b b*,
on either side. It should however be observed, that
the upturned character of beds on either side of dykes
is more rare than a mere division of the stratified or
other rock, without any mark of the violent intrusion of
the matter of the dyke.

In some countries very considerable geological effects have been caused by the intrusion of igneous rocks among others of all geological ages, from the lowest known stratified rock to modern deposits inclusive. Sometimes they seem to have been thrown up in the manner of modern volcanos, accompanied by eruptions of ashes and cinders, either into the atmosphere, or some other relatively small superincumbent pressure ; at others they appear to have been protruded, either in greater masses, or beneath great superincumbent pressure, producing a variety of effects which it would occupy too much space in this brief sketch to enumerate.

It was once supposed that granite was the fundamental rock upon which all others rested. Without entering into the theory which supposes the granitic to be that form of rock which was first produced if the mass of the earth were once in a state of igneous fusion, it may be considered that granite is more, abundant, taken in the mass, among the inferior stratified or non-fossiliferous rocks, than among the fossiliferous class, particularly the more modern deposits of that class. We are not, however, to restrict granite to the lower fossiliferous rocks ; on the contrary, we are not yet prepared to say how high up among that series it may be discovered, since it has been detected above the chalk at Weinböhla, and consequently it must have been ejected from beneath, in that situation, during the supracretaceous or tertiary epoch.

The mass of the igneous rocks appears to be composed, in variable proportions, of the silicates of alumina, magnesia, lime, potash and soda, with the occa-

sional and subordinate presence of a few other sub-
stances ; those rocks being the most fusible in which
silicate of lime is somewhat abundant, while the most
refractory seem those in which silicate of magnesia pre-
vails.   Those in which the minerals named hornblende
or augite (the latter probably only a modification of
the former) abound, such as greenstones, basalts, and
many lavas, are on that account more fusible than those
in which mica prevails, such as many micaceous gra-
nites.   Most granites are however refractory, particu-
larly when quartz is abundant in them.   Serpentine
also is of difficult fusion ; but those rocks in which the
mineral named felspar prevails are not, in general, very
refractory.

    It has been considered that silica is more abundant,
viewed in the mass, among the older than among the
more modern igneous rocks, while lime (as a silicate)
more abounds in the latter.   Many of these rocks may
never have been in a solid state before they were ejected
upon the solid surface of the earth, while others may
readily have been produced by the fusion of pre-existing
solid rock, and then driven to the surface, in both cases,
by sufficient forces acting beneath.

PART II.

As we should, when searching for the causes of any given effects, proceed, if possible, from the known to the unknown, it behoves us carefully to observe the effects of those causes which daily produce geological changes on the surface of the earth, and then, weighing all the circumstances under which the various rocks are presented to our attention, honestly to seek, without bias, to what extent they can explain the production of the different mineral masses which compose the exposed solid surface of the globe. If, after careful investigation, we find that the effects of those causes which are known now to act on and modify the world's surface prove insufficient, or only partially account for, all the phenomena observed, we should endeavour to ascertain the extent to which they are insufficient, and then proceed to inquire how far the supposed greater intensity of similar causes may carry us. Should we still find many phenomena not satisfactorily explained, we must necessarily have recourse to various hypotheses founded on the known laws of nature, waiting until the progress of knowledge generally shall enable us to frame a theory in which the various parts shall be in harmony with each other, and with the whole taken collectively.

I. *Decomposition of rocks.*—There is a tendency in all rocks to decompose by the action of the atmosphere upon them, and to be afterwards carried by lines of

moving water to lower levels than they occupied prior
to decomposition, often into the sea, or other bodies of
water, where they may be distributed in such a manner
as to produce new accumulations of mineral matter, or
new rocks as they are termed, in which the remains of
existing animal or vegetable life may or may not be
entombed, according to circumstances.

a. To appreciate the action of the atmosphere on
given rocks, the observer should direct his attention to
the amount of yearly or other change caused by it on
masses of stone used for buildings, and which are sup-
posed to have been taken from those situations in quar-
ries where such masses have, to a great extent, been
secured from atmospheric influence ; carefully investi-
gating whether the observed changes may have been
caused by the chemical or mechanical action of the
atmosphere, and of the substances accidentally con-
tained in it ;—that is, he should observe whether any of
the component parts of the stone have united chemi-
cally with those of the air or the substances contained
in it, or whether the external parts have been removed
by the friction of water, by the freezing of water in the
interstices of the stone, forcing the component particles
asunder, or the like.   Care should be taken to note the
structure of the stone, ascertaining whether it be homo-
geneous, like compact limestone or marble, or com-
posed of substances which, when exposed to the same
causes of decomposition, resist them unequally, such as
granite, conglomerates, and many sandstones.

Due attention should be paid to the variations of cli-
mate, noting carefully the aspect of the buildings, and
if the same materials are differently decomposed in dif-

ferent aspects, endeavouring to show the reasons of such difference, such as the prevalence of driving rains, or of furious winds, more from one quarter than another.   An antiquary, if he be a chemist, or call in the aid of one, may in this manner afford valuable geological information, without neglecting his more peculiar studies.

b. To estimate what have been the effects of decomposition in surface rocks between the soil, as it is commonly termed, and the more solid parts of such rocks, the observer will have more difficulty ; since he cannot know the amount of time during which they have been exposed to atmospheric influences ; neither can he judge with precision as to the quantity of decomposed rock which may have been removed, nor of the variable character of the vegetation above, by which the decomposition has, according to circumstances, been more or less modified.   Much may, however, be accomplished by careful observation.

Although on high mountains, where masses of rock are frequently exposed to the free action of the atmosphere, they are often greatly decomposed, we cannot estimate the depth to which a given rock has been *weathered*, as it is termed, so well as on lower grounds ; for, on exposed mountains, the form of the surface is generally such that the decomposed parts are readily removed by the action of moving water to lower levels. We might indeed roughly estimate the amount of surface loss sustained by rocks in these situations, by means of the pinnacles and bosses of harder matter which still retain their places, if we could form anything like a just conception of the figure of the moun-

tains after they first occupied their present positions, and before the atmosphere acted upon them. Unfortunately, the stratification of mountain ranges is generally such that the rocks of which they are composed bear evidence of having been greatly fractured when forced into their present positions, and therefore the mountains, for aught we know to the contrary, may even have been more rugged and broken than we now find them.

In the lower lands, for instance on the top of broad-backed hills, where there would be a difficulty of removal by moving water, and where it has been carefully ascertained that transported substances have not been carried, we seem to arrive at more satisfactory conclusions. The observer should search for pits on central portions of the broadest part of such hills, and in them he will often detect good examples of decomposition. Perhaps he may find granite decomposed in

Fig. 22.
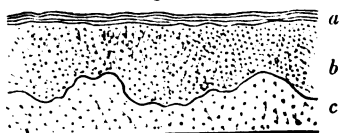
the manner represented in the annexed section (Fig. 22), in which *a* is the vegetable soil, as it is commonly called, *b* decomposed granite, and *c* granite in its solid form. In such a section as the above, he must be careful to ascertain that the particles of granite at *b* are exactly of the same kind as those at *c*, and that there can be no suspicion of their having been carried into their present position by moving water. Sometimes

he may find the granite decomposed so as to leave large
rounded masses of solid granite surrounded by loose
decomposed portions.   The annexed illustration of this
fact (Fig. 23) is taken from part of the road between
Okehampton and Moreton Hampstead, in Devonshire;—
a represents the vegetable soil, *b* decomposed granite,
c c solid rounded masses of undecomposed granite in-
cluded in the decomposed part, and *d d* solid granite.
In such a section as this the observer should use great

Fig. 23.
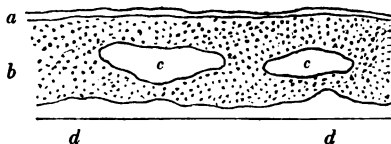
care, so that he may be certain that *c c* are not trans-
ported boulders of granite, included in smaller granitic
gravel, *b*.   Fortunately, in this case, he would be
greatly assisted by the presence of large crystals of
felspar disseminated through all parts of the rock, both
decomposed and undecomposed, and which are beauti-
fully preserved in their relative positions in the former.
In the decomposed granite above noticed, the effect
produced has been chiefly chemical, a change having
been effected in the felspar through atmospheric agency.
    Among a variety of hard rocks, the component parts
of which do not readily combine with any portion of
the air or of the water contained in it, and which are
too compact to allow of any considerable absorption of
water between their particles, considerable decomposi-
tion may yet be produced by the tendency of such

rocks to split into fragments when exposed to the in-
fluence of the atmosphere. The observer may often
trace the breaking up of a compact limestone or hard
sandstone in the manner represented in the annexed
section (Fig. 24), in which *a* represents the vegetable

Fig. 24.
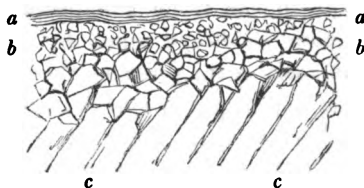
soil, *c c* a hard sandstone rock, such as some varieties
of grauwacke, and *b b* fragments of the same rock,
largest towards *c c*, and evidently constituting portions
of the subjacent strata, while the upper fragments are
smaller and more confusedly mixed, though still an-
gular.

Probably much valuable information might be event-
ually obtained, if, when deep excavations are made for
roads or other purposes, marks of a given depth and
form were cut on the exposed surfaces, with the date
attached ; notes being made of the fresh condition of
the rock when the mark was cut, and of other obvious
circumstances, and the notes placed in some common
place of security. Care should of course be taken to
cut such marks only on such parts of rocks as were not
previously exposed to the direct action of the atmo-
sphere, and therefore as far beneath the decidedly
weathered part as may be convenient, and at the same
time secure from other injuries than those of atmo-
spheric agents.

c. The observer must be careful, in his estimate of the amount of decomposition which rocks may sustain from the action of the atmosphere, duly to consider the power of vegetation to prevent, assist, or otherwise modify it, according to circumstances.   Vegetation may prevent decomposition, by presenting a certain barrier to the effects of sudden frosts and thaws ; assist the mechanical action of heavy rains by keeping the higher parts of rocks more permanently wet than they would otherwise be ; or greatly modify it, by the various effects produced according to the kind of plants which may cover the land at given times : for a portion of country covered by forest-trees would be differently circumstanced, as regards the probable decomposition of the rocks of which it is formed, than when the same portion was either broken up for tillage or covered by pastures.

II. *Removal of parts of pre-existing rocks by moving water.*—The decomposed parts of rocks above noticed are necessarily of different sizes, according to the kind of solid rock whence they have been derived, and the circumstances to which their present condition is due.   The angular fragments of hard limestone or sandstone, such as are sketched in Fig. 24, would offer greater resistance to any given force of moving water than a fine-grained decomposed sandstone : that is, supposing the same heavy storm of rain to fall equally on both, the loose sand of the decomposed sandstone might be washed away, while the large angular frag-ments of limestone might remain firm : or, supposing the two different kinds of decomposed rock to be equally exposed to the force of the same rivulet or

river, the one might be carried down the stream, while the other remained in its place.

a. When an observer is desirous of estimating the power of any particular stream or river to carry forward the detritus of pre-existing rocks, formed either by decomposition or by the abrasion of moving water, to be noticed hereafter, he must be careful to take several circumstances into consideration.

1st. The various slopes of the channel should engage his attention; for moving water carries detritus forward according to its velocity, and the latter neces-

Fig. 25.
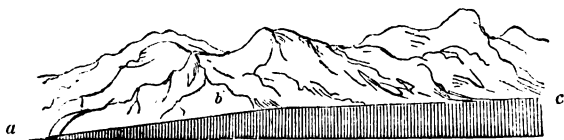
sarily increases with the amount of the slope : that is, if *a b* (Fig. 25) represent the exaggerated slope of a river in one place, and *b c* the slope of the same river in another, and the amount of water be neither increased nor diminished by tributary streams or diverging branches, the river will run much quicker at *a b* than it will at *c b*, and consequently smaller pebbles or finer sand can remain at the bottom of the latter than the former, because the force of the water would wash away much larger pebbles or sand at *a b* than it can at *c b*.

2ndly. The shape as well as the size of the detritus should be taken into account; for two fragments of the same rock, though exactly of the same size, or volume,

as it is termed, may be carried forward by different forces of moving water, if their shapes be different. A common angular fragment of a given rock, for instance, would not be moved at the bottom of a river, when the force of the water was only sufficient to roll on a piece of the same rock of a globular shape, though the two pieces should be of exactly the same size or volume.

3rdly. The relative weights, or specific gravities, of the different kinds of pebbles or fragments of rock should be duly considered; for the force of a river only sufficient to move one kind of pebble or fragment, would be unable to move others of greater weight or specific gravity, though their shape and size were the same. The stream of a river which could only move a ball of marble three inches in diameter, could not carry onwards an iron cannon-ball of the same size, supposing both placed under exactly the same circumstances.

If we knew the velocity of water required to move fragments of given size, shape, and weight, the observer would obviously only have to ascertain the velocity of any river he may have under examination, and he would at once obtain the kind of detritus which it could carry onwards. On this head, unfortunately, we possess little information which can be deemed satisfactory, and therefore direct experiments should be made to clear up the subject. We know, that if $a\,c\,b$ (Fig. 26) represent the section of a river-course, the
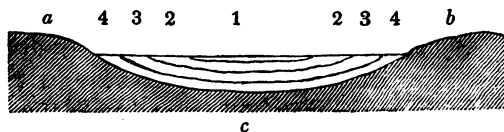
greatest velocity will be at 1, and that it will decrease towards the sides and bottom, as may be represented by the layers of water, 2, 2; 3, 3; and 4, 4; but we do not know the law of this decrease, nor the amount of friction that we ought to have at the bottom and sides, when we have a known velocity of current in the middle (1), and when the depth of water, distance from the sides, and shape of the river-bed are also correctly ascertained. We should anticipate in such a section as that above (Fig. 26), that the friction of the same layer of water, next to the sides and bottom, would not be equal at the banks *a b*, and at the bottom *c*, since the weight of water would be greater at the latter than at the former.

b. The checks which a river may suffer in its course should be duly noted, such as lakes, patches of level land, and the like. Without this precaution it might be, and indeed has been, inferred, that all the pebbles found far down the course of all rivers have been swept onwards by the existing rivers. In some cases this may be true, but in many it is not so. Frequently, when a river takes its rise in high mountains, its course onwards is, though often rapid, interrupted by tracts of level country, or even lakes, where the larger detritus is arrested; and yet pebbles derived from the rocks of the high mountains are found abundantly in the river-bed farther down than these obstacles, such pebbles having been brought down from the higher levels by pre-existing moving water. Thus Alpine pebbles in some of the rivers of Northern Italy could not have been carried into the plains of Lombardy by existing rivers, since the Lago Maggiore, the Lago di Como, and

others, necessarily stop the progress of the pebbles borne from the high Alps by the torrents which feed the lakes.

c. The proper time of estimating the transporting power of a river is during heavy floods, when fragments of rocks can be moved which would remain firm under ordinary circumstances. The observer should endeavour to separate the complicated effects of a flood in a cultivated country from each other, carefully weighing how much is due to the increased velocity of the river; to bodies of water ponded back by obstacles which give way before the pressure exerted upon them; to the transporting powers of sluices of water thus suddenly set in action; and to various other obvious circumstances:—in fact, endeavouring to ascertain what is really accomplished by the velocity of the water, by its weight and volume, or by the united action of its weight, velocity, and volume. He will thus avoid massing all the effects together, and by so doing attribute to one power that which is really due to another.

d. The transporting power of a current or stream of tide passing along a coast is, to a certain extent, the same as that of a broad river on the line of one of its banks. If, in imagination, we withdraw the other bank and substitute the open sea, moving in the direction of the river, we have a stream of tide or a current acting on a coast, and, of course, we have the same laws in force. The friction of the water on the land would retard its progress, and the power of the stream to remove loose matter would depend upon its velocity. Although the projecting headlands or capes would be most acted on, in the same manner as the obstacles to a

river's course, the action of a given velocity of water
on a hundred miles of coast would be greatly less ,than
on the bank of a river also one hundred miles long,
all other circumstances being equal : for in a river, the
stream of water, when thrown off by one bank, is again
thrown on it by the other ; whereas, on an open sea-
coast, it rarely happens that any obstacle throws a stream
of tide back again, when it is fairly driven off from the
coast, by a cape or headland. It therefore follows that
there would be less transporting action, viewed strictly
with regard to equal velocity of water alone, on a line
of sea-coast than on the bank of a river, all other cir-
cumstances being equal.

The proper time to study the effects of a current or
stream of tide acting on a coast, is when the sea is per-
fectly calm,—that is, unruffled by waves. The observer
should be careful to attend to this, as from want of due
caution, the complicated action of the sea and atmo-
sphere on coasts has often been attributed to the action
of one cause only out of several causes. Streams of tide
or currents undoubtedly run stronger when forced for-
ward by strong winds, and due allowance should be
made for the increased velocity in such cases ; still, when
we observe a coast at such times, we must carefully sepa-
rate the action of the waves from that of the mere fric-
tion of the moving body of water.

III. *Abrasion of rocks by moving water.*—It will
be evident to those who observe a body of clear water
driven against some of the softer rocks, that water has
the power, when its volume and velocity are sufficient,
to abrade rocks. This power is greatly increased when
bodies of moving water, such as rivers, are charged with

detritus, since the friction is then greater. The observer should direct his attention to the various circumstances by which abrasion of this kind is effected.

a. If the moving water be a river, the amount of decomposition which a rock may have suffered, before acted on by the river, should be carefully estimated, so that the power of the river to abrade a given rock may not be over-estimated. As it is found that the decomposition of many rocks is greatly assisted by being kept alternately wet and dry, the observer should see whether the water of the river rises and falls in a manner sufficient to have an appreciable influence on the rocks washed by it.

b. In situations where we have reason to suppose that deep cuts or ravines have been formed by existing rivers, it is necessary to weigh well all the circumstances which may have attended such instances of abrasion. If a barrier, such as a lava-current, be suddenly thrown across a valley, the waters behind are necessarily sustained to the height of the lowest part of the obstacle thus opposed to their further progress down the valley. Now, when a section such as that annexed (Fig. 27) is presented to our attention, where

Fig. 27.
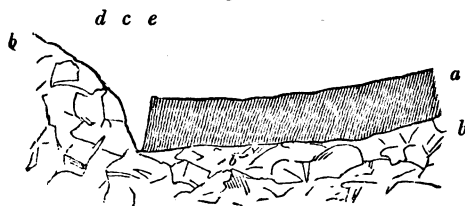
a lava-current, a, has flowed into a pre-existing valley of granite, $b\ b\ b$, and we find a ravine, c, through which a river flows, we must not too hastily conclude that the whole depth of the ravine has been produced by the erosive action of the river, since it may easily have happened that the lava-current, a, never completely filled up the valley, but that a space was left between the high part, e, of the lava, a, and the bank of granite, d. We might, *à priori*, infer that there would be an open space at c, resulting from the contraction of the mass of the lava-current, a, by cooling. Neither should we conclude, supposing the lava did rise to a proper height against the granite bank, d, that the same body of water would in the same time cut through the lava-current itself to the same depth, since, in the case of the section before us, the river in the ravine, c, would not only act with considerable advantage on the line of separation between the two rocks, but in all probability the outer side of the bank of granite, d, would have suffered by weathering, or the action of the atmosphere upon it, before the lava-current traversed the valley. When, therefore, the abrading power of the river was brought to act violently upon it, as would be the case under the circumstances above noticed, its destruction would not afford a satisfactory measure of the action of the same force of water on the solid granite during the same time.

c. Before the observer concludes that any ravine he may find has actually been cut by a river now flowing through it, he must be certain that the ravine is not the result of a great crack in the rocks which constitute its walls. When, therefore, he discovers a ravine which

Fig. 28.
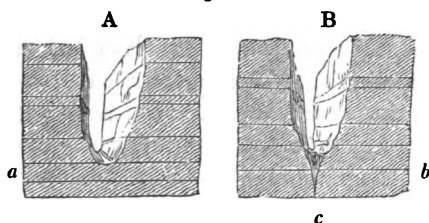
appears to have been cut by the abrading power of the
river in it, he must carefully look for good evidence
that it is not a crack, for such is not unfrequently the
case.   Let A and B (Fig. 28) represent two sectional
views of two ravines, and let us suppose an observer
placed in either endeavouring to ascertain their origin;
he might conclude, from their general appearance alone,
either that they were cut by the rivers in them, or were
cracks, as best accorded with his preconceived opinions.
To clear up this point, he must see if the two sides of
the ravine are in any manner connected by a ridge or
ledge of rocks.   If he find one, he should in the next
place ascertain whether any bed of rock, such as *a*, goes
clearly across the river and is unbroken; because, if un-
broken, he has direct evidence that the ravine is not
due to a crack, but is an excavation in the body of the
rock, as shown at A.   If, on the contrary, he find no
marked bed of rock extending continuously across the
river, the evidence is uncertain; for the blocks, pebbles,
or sand, as the case may be, in the river-course, may
either cover such continuous beds, or the head of a
crack such as that represented at *c* in B.

In the above sections (Fig. 28) we have made the rocks to correspond on either side of the valley, for the sake of more easy illustration. Should, however, the observer find the beds of rock on either side of the ravine so situated as to relative levels that they would not join, though horizontal, if prolonged towards each other; that is, if he discover, as in the annexed section (Fig. 29), that a horizontal and marked bed, *a*, was

Fig. 29.
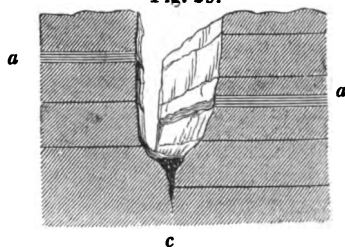
higher on one side of the ravine than on the other,—he would at once perceive that the river has worked upon a crack, *c*, and that probably there has been compound action productive of the ravine — first, a crack in the body of the rock, and secondly, abrasion by running water along the line of the crack or fissure. Should he also find, supposing the beds of rock vertical, that they would not respectively meet if prolonged in the lines of the beds towards each other, he would infer that the body of rock had been dislocated, and that the river, if there be one, ran upon the line of dislocation. Let the annexed figure (Fig. 30) represent a map-sketch of a ravine, *a b*, through which a river flows, the various beds of rock on either side being vertical,

D

Fig. 30.
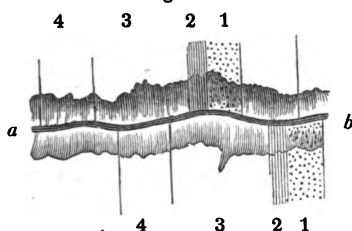
instead of being arranged in horizontal layers, as in Fig. 29. Should the observer find upon examination that a marked series of beds, 1, 2, 3, 4, would not meet if prolonged across the river, as represented above (Fig. 30), he will then know that the whole body of rock has been dislocated, and that the river runs in the line of fracture.

When, however, an observer is certain that any ravine is the higher part of a greatcrack or break in the continuity of the rocks on either side, he will still have to estimate the probable abrading effects of the river flowing upon such a crack or break, weighing well the general condition of the channel, the hardness of the rocks composing the walls of the ravine, and of the pebbles and pieces of rock forced down by the river, particularly during floods.

d. When there is reason to suppose that a lake has once existed in some principal line of valley, either from there having been a rise of the general bottom at one particular place, or that a lava-current has run across the valley, damming up the descending waters, and that the waters of the lake have been drained by gradually working down the barrier,—the observer must

study the probable height of the dam before it was cut through, in order to obtain an estimate of the body of water kept back, the amount of fall to the lower levels, the velocity of the descending waters, and the force of the abrading power. Let the annexed diagram (Fig. 31)

Fig. 31.
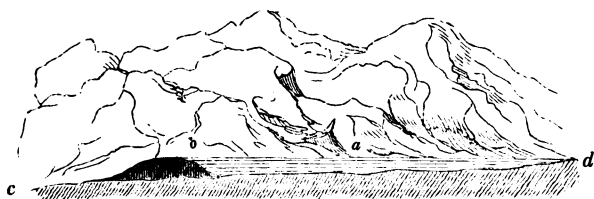
represent the longitudinal section of a lake, *a*, kept back in some principal valley by a lava-current, *b*, which has crossed it ; then the height of *b* above *c* (the channel of the river below the obstacle *b*, and form-ing part of the former continuous channel *c d*,) would afford an estimate of the velocity with which the sur-plus waters of the lake, *a*, would rush towards *c*, and consequently of its abrading powers.   This velocity, and consequently the abrading power, would decrease as *b* was gradually cut through, and the amount of fall became less.

e. The observer should not neglect the abrasion by minor streams and heavy falls of rain ; for though it may not at first sight appear very considerable, yet, col-lectively viewed, small streams of water carry forward a great body of the smaller detritus to lower levels, where it is either accumulated in favourable situations, or transported onwards by the principal rivers, which throw much of it into the distributive power of the

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sea. In the tropics, the observer will find the abrading power of a few hours' rain very striking, particularly in those favourable situations where there is no protection from the dense vegetation so common in such countries.

f. There has been scarcely any power more over-rated by geologists, since attention has been paid to facts, than that of marine currents and streams of tide to abrade the coasts which they wash, and to excavate valleys in the bottoms beneath them.   This seems mainly to have arisen from a want of correct observation, and sometimes from the absence of any definite idea of the power theoretically called into action. Hence have arisen the almost inconceivable errors respecting the geological effects produced by such agents. The attention of the observer has been called above to the transporting power of currents and streams of tide. To estimate the abrading effects of these powers, he should well weigh the velocity of the waters thus thrown into motion, the depth to which such velocity extends, and the retardation of the moving water as it approaches the coast or bottom, where, in point of fact, its abrading power begins.   Duly to estimate the amount of abrading action, the observations should be made at the seasons and times when the currents or tides are in full force, and yet when the sea is perfectly calm.   They should also be made at the junction of the water with the land, where alone any abrasion can take place.   It may be almost needless to remark, that the proper time to estimate the abrading power of a tidal stream is during *high springs*, as they are technically termed, when the streams of tide run strongest.

IV. *Abrasion of coasts by waves.*—We may here

notice this power, which is the greatest land-abrading force with which we are acquainted, particularly when its effects are collectively considered.

a. Properly to estimate the effects of this power, the observer should be present on some exposed coast, such as that of the western part of Ireland, the Land's End, Cornwall, or among the Western Islands of Scotland, during a heavy gale from the westward, and mark the crash of a heavy Atlantic wave when it strikes the coast. The blow is sometimes so heavy that the rock will seem to tremble beneath his feet. He will generally find in such situations, that though the rocks are scooped and caverned into a thousand fantastic shapes, they are still hard rocks ; for no others could continue long to resist the almost incessant action of such an abrading force. Having witnessed such a scene, he will be better able to appreciate the effects, even though the waves be far inferior in size, upon the softer rocks of other coasts.

b. The observer should carefully remark the direction of the prevalent winds, and the proportion of those which send the greatest waves, or seas as they are termed, on shore, in order that he may duly appreciate the loss of coast sustained in those directions where the force of the breakers is greatest and most incessant. Thus, on a coast on which western winds prevail, and there is a sufficient extent of open sea before it, we should expect to discover the greatest amount of destruction produced on points exposed to the westward, while rocks of equal hardness might be less abraded in places open to the eastward.

c. The attention of the observer should be directed

to the rise and fall of tide on tidal coasts, when esti-
mating the abrading power of waves on such coasts ;
since a greater surface of rock, all other things being
equal, is exposed where the rise and fall are great, than
where they are small.   Moreover, the rock is exposed
to greater decomposition from being alternately wet
and dry, in proportion to the surface so wetted and
dried.   It must not, however, be forgotten that coasts,
where breakers reach the cliffs at high water, are fre-
quently protected by beaches at low water ; and that
therefore they are removed from the abrading power of
the waves during all the time that they break on the
protecting beaches—a time which varies with the vary-
ing state of the tides and the state of the weather gene-
rally.

   d. An observer will scarcely have long directed his
attention to the abrading power of waves breaking
on coasts, before he will discover many circumstances
which modify the effects that would be otherwise
produced.   He will see that the abrasion of coasts
is often greatly assisted by land-springs, as they are
termed, that, as it were, shove the cliff into the
power of the breakers by moistening a body of rock,
which thus loses its cohesive powers and is launched
in the direction of least resistance, or seaward.   Other
encroachments are made by the fall of masses of cliff
undermined by the waves, the cohesive power of the
rock not being equal to its weight or the action of gra-
vity downwards.   If, as in the annexed sketch (Fig. 32),
a rock be even sufficiently cohesive in the mass as to
admit of the considerable excavation there represented
without falling, a time must come, if the breakers con-

tinue to work on in the same direction, when the
weight of the superincumbent mass would be such that
it must fall.

Fig. 32.
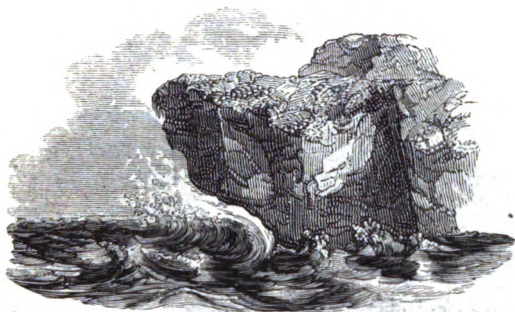
When, however, a great mass of cliff does fall, in the
manner noticed above, the observer should direct his
attention to its conservative influence.   To appreciate
this, he will consider the hardness of the rock, the posi-
tion into which it has fallen, and its new power of

Fig. 33.
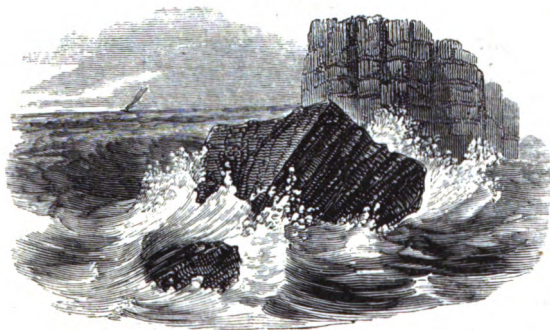
breaking the waves farther from the coast.   If the mass
of fallen rock be stratified, much will depend upon the
face presented to the breakers ; for if it fall so that the
plane of the beds remains sloping seaward, as in Fig.
33, it will act as a well-contrived wall erected to defend
the cliff: but if the beds should be exposed vertically

Fig. 34.
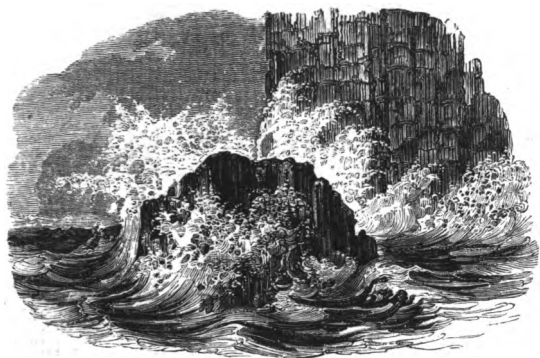
after the fall, as in Fig. 34, the future destruction of
the mass would be far more rapid, and its conservative
influence consequently less.

While on this subject, it may be noticed that incrus-
tations by marine animals and seaweed tend greatly to
protect the bases of cliffs on tidal coasts ; and the ob-
server should particularly direct his attention to the
conservative influence of the *Balanus* in many situ-
ations.

e. The observer will sometimes find, when a soft
rock forms the base of a cliff, and a hard rock the upper
part of it, that the fall of masses of the upper part,
in consequence of being undermined, will protect the

lower part from further destruction for a time depend-
ing on various circumstances.   Let the annexed dia-
gram (Fig. 35) represent the section of a cliff, the

Fig. 35.

upper part of which is composed of a hard rock, *a*,
resting upon a softer rock, *b;* then the action of the
sea, *d*, upon the cliff would undermine it, and cause
the fall of masses of hard rock, *c*, which thus accumu-
lating at its base, would protect it, according to the
quantity of rock fallen, the size of the masses, and their
hardness.   The observer will find that such fallen por-
tions of the harder parts of cliffs, whether they be frag-
ments of harder superincumbent rocks, or indurated
concretions of softer beds, greatly modify the abrading
power of the breakers on a coast, particularly during
the lower states of the tide.

f. The actual power of breakers to triturate frag-
ments of rocks according to their hardness, and conse-
quently the relative powers of given rocks to resist such
action, may often be roughly appreciated in beaches
collected in favourable situations.   Great care should,
however, be taken to pay due attention to the circum-
stances attending the production of the beach, and
more particularly to feel assured that pebbles derived
from any conglomerates which may exist in the vicinity
are not mixed with fragments of the same kind of rocks

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detached in the present day from the cliffs on the exist-
ing line of coast.   The same remark applies to rounded
gravels brought down by neighbouring rivers, or washed
out of the cliffs.

   g. When an observer attempts a general estimate of
the abrading power of waves on an extensive line of
coast, he will do well to direct his attention, not only
to the relative hardness of the rocks composing it, but
also to the position of the beds, if the rocks be strati-
fied.   He will not fail to perceive how frequently lines
of coast, under otherwise equal circumstances, depend
on the direction and dip of the strata.   Their position
with respect to the force of the sea is necessarily import-
ant ; for if a series of beds such as those in the annexed
sketch (Fig. 36) dip seaward, the action of the sea
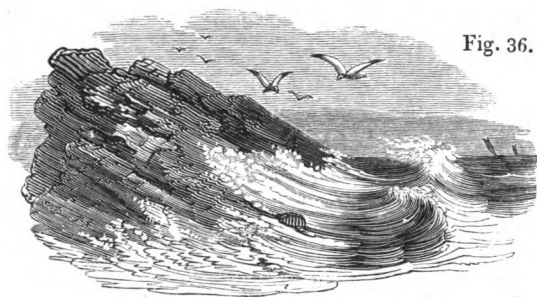
Fig. 36.

upon them can be but relatively trifling, since the return
of one wave down the slope diminishes the force of the
next falling on the coast, and what remains of it is
gradually expended by running up the slope, in which
there is no projecting part to offer resistance to its
course.   The positions in which the edges of the beds
of any given rock are exposed to the action of the

Fig. 37.

N

W
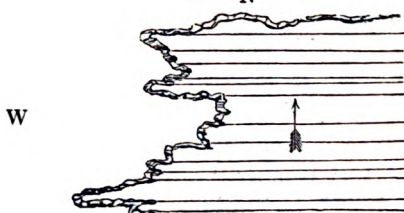
breakers, are those where the loss by abrasion is greatest. Let us suppose that the annexed sketch (Fig. 37) represents a line of coast exposed to the North and West, and that the abrading power of the waves is equal from both points; then the real effect produced will depend upon the resisting powers of the rocks themselves. If we now suppose the country composed of any given rock, such as grauwacke, and the direction or strike of the beds from E. to W., and their dip about 45° to the N.; then the resisting powers of the rocks will be great on the north coast, since the beds shelve seaward in that direction, while the same rocks will be exposed to much abrasion on the west coast, since the edges of the beds are exposed in that direction, and numerous indentations will be the result.

Even in cases where beds of rocks on coasts shelve seaward, the abrading power of the breakers is still frequently apparent. The sea often works upon the land by means of the cleavage fissures of the rocks themselves, or on the fractures caused by faults : nevertheless, the protecting power of strata which do thus shelve is always sufficiently observable.

h. The observer would always do well to inquire from aged fishermen and others, on coasts where he suspects the loss of land has been great within the

memory of man, how much has gone within their recol-
lection; not contenting himself with loose generalities,
but compelling specific answers as to the actual quan-
tity lost, with their recollection of what was done with
such portions before they were removed by the action
of the sea. The author has sometimes been told of
vast losses in this manner, which have subsequently
turned out to be relatively trifling , while, on the other
hand, they have sometimes been underrated. Little
dependance can be placed on old maps of coasts, which
are for the most part exceedingly inaccurate ; indeed,
there would be no difficulty in producing those which
would, when compared with a modern good survey,
show an increase of half or three quarters of a mile on
a coast where, in point of fact, there had been consider-
able loss.

V. *Mechanical deposit of detritus in river-courses
and on plains.*—From the various causes above no-
ticed, a large collective amount of detritus, or variously
sized portions of pre-existing rocks detached from them
by decomposition or abrasion, is mechanically suspend-
ed in moving waters, from which it is precipitated
under favourable circumstances.

a. Fully to appreciate the distance to which the
various kinds of detritus may be carried by moving
water, until they be deposited, an observer should di-
rect his attention to the quantity and kind which can
merely be pushed forwards by a given velocity of such
water, acting on the bottom or sides over or against
which it may flow, and to the quantity and kind the
same velocity may keep mechanically suspended at the
same time. In the former case, the friction of the

water on the bottom or sides is the cause of the for-
ward motion of such detritus ; while, in the latter, the
particles of detritus are, as it were, shaken up among
the particles of water by sufficient velocity and agita-
tion, upon the same principle that fine silty matter,
placed in a bowl of water, is shaken up into the
water by agitation.   As the silty matter remains me-
chanically suspended in the water of the bowl as long
as the necessary agitation continues, so does rock detri-
tus continue mechanically suspended in larger bodies of
water until the agitation be insufficient to keep it so
suspended, when a settlement takes place.

b. The observer will not fail to remark, that in tor-
rents rendered turbid by the wash of detritus into
them, from heavy falls of rain or other causes, the water
is in a constant state of agitation, and that silt and
sand are only deposited in those places where this agi-
tation is insufficient to keep them mechanically sus-
pended.   Moreover, he will see that upon the amount
of velocity and agitation depends the size of the detri-
tus which can be carried forwards.   Some of this detri-
tus is mechanically suspended in the torrent, while
other portions, necessarily the largest, are pushed for-
wards by its friction against the bottom and sides.
Two causes therefore are in operation at the same time,
both tending to carry portions of pre-existing rocks to
lower levels.

c. When an observer detects detritus of a particular
kind disseminated through moving water, he must not
too hastily conclude that the velocity with which the
water is then flowing is sufficient to keep such detritus
permanently suspended ; that is, that such detritus

would continue to be mechanically suspended so long
as such velocity remained the same.   Detritus dissemi-
nated in still water experiences a mechanical difficulty
in descending to the bottom in proportion to its fine-
ness.   The same law holds good in moving water;
though probably such difficulty is increased in propor-
tion as the velocity of the suspending water increases,
until finally the velocity be sufficient to keep it me-
chanically suspended.   There will, however, evidently be
a point where the power of mechanical suspension from
agitation ceases, and the power of settlement begins,
the latter increasing as the moving water is gradually
brought to rest.

   d. Attention should be directed to the appearances
of deposits caused by the various modes in which they
may be effected.   A deposit resulting from the pushing
process, itself arising from the friction of moving water
on the bottom or sides over or against which it may
pass, would necessarily present a different appearance
from one gradually formed by the settlement of mud,
silt, or sand in still water.   The pushing process would
continue as long as the pushing power of the water
continued,—or, in other words, as long as the moving
water possessed sufficient velocity and weight.   An ob-
server may estimate the power of a river to push detri-
tus along its course by examining the pebbles and sands
in its bed, due regard being paid to various circum-
stances previously noticed, and a knowledge having
been obtained of the various rocks existing in the
course of the river.   Let the annexed sketch (Fig. 38)
represent the course of a river, *a b*, through a country
composed of marked rocks, *c c, d d, e e,* into a low
country *f f,* where its movement becomes sluggish; and

Fig. 38.
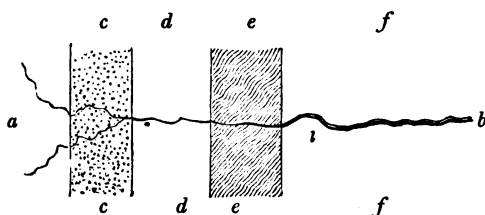
let the fall of the river-bed from *a* to the low country
be sufficient to produce a stream capable of pushing
forwards pebbles of the size of an egg, where its full
force can be directed against them.   If the river be
capable of forcing such pebbles onwards, it follows that,
all other circumstances being equal, it can drive for-
wards those of less size, and that finally there will be a
size which the velocity of the river can keep mechan-
ically suspended in its waters.   There will necessarily
be a deposit of the detritus pushed forward wherever
sufficient obstacles present themselves ; and as the river
would vary in its power to do so according to the quan-
tity of water in it, such deposits would possess an irre-
gular character somewhat resembling the annexed sec-
tion (Fig. 39), depending on small shifts in the direc-
tions and force of the propelling current.

Fig. 39.
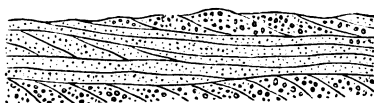
    In the sketch (Fig. 38) we have supposed the river
capable of propelling pebbles to the commencement of

the low ground, *f f;* therefore the observer would look for irregular accumulations of gravel and sand at *l,* where the more level channel of the river commences, and the ability of the moving water to shove pebbles onwards ceases.   He would not, however, expect the finer silt and mud to be also there accumulated ; since, though the power to keep such detrital matter mechanically suspended would be gradually lost by the river, the time required for its settlement, particularly of the finer parts, might be such that the whole body of water may continue to move down through the lowland in a turbid and discoloured condition, slowly parting with the detrital matter disseminated through it ; the agitation of the moving water being frequently such as to keep the mud and silt suspended until the whole be stopped by a body of still water, such as a lake or the sea.

e. A deposit of transported detritus could not be otherwise than produced along the line of a river under the circumstances above noticed ; and hence we should expect, unless such deposits were cut up by floods and thus carried still farther forwards, that the bed of the river would be raised.   To this circumstance the attention of an observer should be directed.   For the most part, the power of a stream to keep its channel clean, and even to work it deeper, after the principal hollows are filled up, is obvious where it runs with rapidity ; but where it changes from rapid to slow and sluggish, it will be often found to raise its bed by the accumulation of detritus which has been gradually *shoved* from the higher levels downwards.   In broad plains much alluvial matter seems to have been collected

by the raising of channels, and the tendency of the
rivers to quit such raised beds and flow in lower levels,
which are in their turn also raised, so that eventually
the whole plain acquires a certain additional increase
in height. It follows, that if, in such rivers as tend
to raise their beds, artificial embankments be formed,
the rise of bed will be more rapid than where the detri-
tus can, during floods, be forced off on either side upon
the lower levels. Now this is found to be matter of
fact, and the traveller in many parts of Italy will be
more particularly struck with it, because the plains of
that country have been long under cultivation, and it
has been necessary to protect such lands for an equal
length of time from the ravages of the rivers which flow
among them. This having been accomplished by con-
tinuing to raise the embankments in proportion as the
river raised its bed, the road across some of these rivers
traverses a corresponding line of elevated ground.

f. It must not be supposed that the sands, clays,
and gravels, often termed alluvial, of all great plains,
have been produced by the deposition of detritus brought
down from higher levels by rivers; because, from the
organic remains detected in such sands, clays, and
gravel, we have often evidence that some have been
produced beneath the waters of a sea, and others appa-
rently in those of lakes. Moreover, fragments of rocks
contained in the gravels of level lands are sometimes of
kinds and magnitudes which could not have been drift-
ed into their present situations by existing rivers. An
observer therefore, before he concludes that the sands,
clays, or gravels of any given plain have been accumu-
lated from detritus deposited by existing rivers, should

carefully search for sections of the level land, either along the banks of the river itself, in the gulley watercourses which communicate with it, or in artificial excavations, such as wells and the like. He should in such situations search very carefully for organic remains, because frequently the kind found will afford him valuable information. He should also search among the pebbles of gravel beds, and see whether there are any derived from rocks not comprised within the present drainage of the country, by the existing rivers or their tributaries, to the spot examined. Even when he finds no other pebbles than those of rocks comprised within such drainage, he should carefully consider whether they could, from their magnitude or other circumstances, have been brought down to their present localities by any force of water which could reasonably be attributed to the existing rivers even during extraordinary floods.

g. There are few persons, probably, who have not remarked that rivers are greatly disposed to serpentine in level countries. A small obstacle seems readily to have diverted their courses when they first flowed in such situations. If the velocity of such serpentine

Fig. 40.
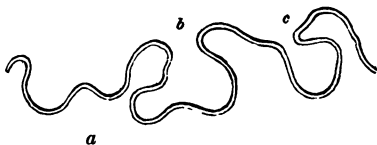
rivers be sufficient to abrade their banks, they will necessarily work most effectually at the bottom of each bend, because there they meet with the greatest obsta-

cles to their onward course.   Hence, if two bends are
opposite to each other, as those of the river in the
annexed sketch (Fig. 40) are at *a*, *b*, and *c*, they will
tend to approximate to each other and finally to meet,
when the channel of the river will be shortened by the
amount of the bend.   Changes of bed thus produced
are, as is well known, common in the Mississippi, and
must of necessity take place in any river where similar
circumstances occur.   By this process, considerable shifts
of the detritus brought down by a river may be effected ;
and consequently, if there be any resulting deposit over
a plain, it will be of an exceedingly irregular character.

   h. When an observer sees a tract of level country
flooded, or covered by the turbid waters of a river which
has overflowed its banks, he should endeavour to appre-
ciate the quantity of solid matter that would be added
to the land, if the waters subsided so gradually as to
permit the deposition of a large portion of the fine
detritus disseminated through them.   He may estimate
the amount of solid matter thus held in suspension over
a given area at any one time, by procuring some of the
water in a vessel holding a given quantity,—a cubic foot
for instance,—and after allowing the turbid water to
clear itself by precipitation, by ascertaining the relative
amount of the precipitate; so that by calculating the
depth of the water over the flooded area, and the
size of the area itself, he would obtain the amount of
solid matter which *might* be added to a particular

Fig. 41.
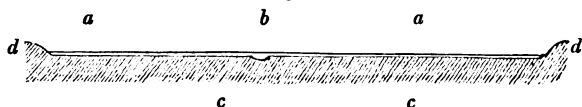
piece of lowland country by any one flood. If the annexed section (Fig. 41) represent that of a level plain, *c c*, through which a river, *b*, passes, which has overflowed its banks in consequence of heavy rains, and spread out in the directions *a* and *a*, until it is stopped at the rising lands, *d d ;* then, during the subsidence of the river-waters generally, it can scarcely happen but that a considerable portion of the turbid waters would find their way back into the river-course, *b*, and thus, admitting a small general deposit while the whole body of water was kept up, the flat land would not gain the addition of precipitated detritus which might at first sight be supposed.

The case will, however, be different, if, as in the

Fig. 42.

annexed section (Fig. 42), a river, *b*, has raised its bed, so that there are large tracts of country at a lower level on either side of it. If a flood takes place in such a river, spreading over the adjoining ·country in a sheet of turbid water, *a a*, until stopped by rising lands, *d d*, then *all* the solid matter disseminated in such sheets of turbid water, below the level of the river-banks, would be deposited on the lands which they cover ; and there may be an additional quantity obtained, if, when the whole country was flooded, the level of the general sheet of water was above that of the river-banks ; since, before that portion which rose above the level of the banks found its way back to the river-course, sediment may have been precipitated from it.

Viewing this difference in the cases noticed, an observer will do well to ascertain whether or not the bed, or rather the banks of a river in a plain, do or do not rise above the level country generally.   This is of necessity a delicate operation when plains are extensive; but it should be strictly attended to when we wish to estimate the amount of fine solid matter which may thus be spread over extensive tracts of low lands, such as the plains of India.

i. Before we pass on to another subject, it may be necessary to call the attention of the observer to those accumulations of detritus which are often brought by transverse tributaries into the main rivers of mountain-ous districts.   If the tributary deliver itself with its full force at the same level, or nearly the same level, into the main stream, then there is generally no great accumulation of detritus, except under extraordinary circumstances, such as a heavy fall of rain in the country drained by the tributary, which is not felt higher up the main stream ; for then, by the increased transporting power of the tributary, a body of detritus may be driven into the main river which it cannot remove, so that in extreme cases the latter may even be dammed up for a time, and a debacle be the consequence, when the main river overcomes the resistance opposed to it, and drives the loose detritus before it.   When, however, as in the annexed sketch (Fig. 43), the tributary comes through a lateral gorge, at a level considerably above the main river, it tends to deposit the detritus it may force forward in the form of a half cone, or one divided perpendicularly to its base.   This form it will retain if the main stream be not so close as to work upon its base and carry it away ; and in favourable situations, such

Fig. 43.
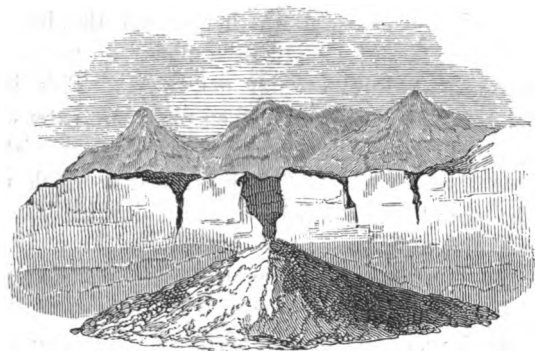
as in some parts of the Alps, cottages and cultivation will be seen in those parts of the mound where the more or less divided streams of the tributary do not rush furiously onwards to the lower levels. An observer will do well to direct his attention to the mode in which angular masses of rock, both great and small, are mixed up, pell mell, with clay, sands, rounded pebbles, fragments of trees, &c. in these accumulations, which are sometimes considerable ; since it may assist him when he comes to consider the probable origin of various kinds of conglomerates among the older rocks.

VI. *Deposit of detritus in lakes and seas.*—As the greater number of rocks divided into beds, and hence termed stratified, are supposed to have been formed by the deposition of sediment beneath the waters of lakes and seas, it becomes important carefully to observe the manner in which rock detritus brought by rivers, or derived directly from coasts, is thrown down on the bottoms of the present lakes and seas. In such cases as are concealed from sight, and which unfortunately

are somewhat numerous, the observer should endeavour to approximate as nearly as possible to the truth, by carefully weighing the various circumstances which may produce the deposit of sediment in such situations, due regard being paid to the operation of local modifying causes.

a. An observer may derive much information as to the mode in which detritus is pushed forwards by rivers into bodies of still, or comparatively still, water, by watching sand carried down by a rivulet into a pool of still water, where the sand is no longer forced onwards, and where it consequently accumulates. It is obvious that similar effects may be obtained by casting loose sand into a stream of water, the velocity of which enables it to push such sand forwards to a still pool into which the rivulet delivers itself. It will in either case be found that little heaps of sand are formed where the rivulet enters the pool, and that the accumulated sands tend to arrange themselves so as to constitute little truncated semicones, if we may be allowed the expression, on the fan-shaped tops of which the channels, over which the moving water pushes the grains of sand, are continually shifting. If, in the accompanying sketch (Fig. 44),

Fig. 44.
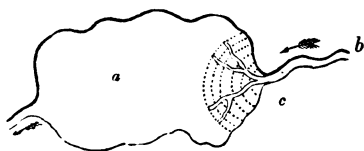
a represent a pool of still water into which a rivulet, *b*, pushes forward sand, then such sand will be found to

accumulate at c, falling down into the pool, a, in such a manner that a little truncated semi-conical heap of sand is produced, which increases superficially, as is shown by the concentric lines at c.

If now the observer direct his attention to the vertical manner in which the grains of sand are accumulated, he will find that they arrange themselves as in the annexed section (Fig. 45), in which a represents the

Fig. 45.
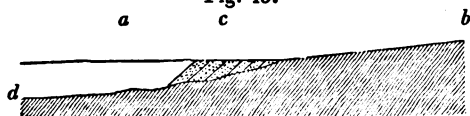
surface of the pool, d its bottom, b the slope of the rivulet pushing forward the grains of sand, and c successive coats of sand formed by the grains falling over into still water, such grains supporting each other at angles of 45° or less, according to circumstances, in the same manner as may be seen in any rubbish-heap from the top of which rubbish is continually thrown over. The velocity with which the grains of sand are forced forwards by the rivulet will cause the successive coatings of sand to be inclined at a less angle at first than afterwards ; for as the little heap accumulates, and its flat top becomes extended, the force of the stream will, from the division of the water into minor parts and the diminished inclination of the channels, become less where the grains of sand fall into the pool, and consequently they will be pushed with less force to the edge and fall more lightly over. It will also happen that the little stones, which the stream may be able to shove forwards during the production of the first layers of the little

heap, the rivulet may be unable to push over the flat top of the latter after it has become somewhat extended into the pool.

If, when the heap of sand has been accumulated to the extent desired, the water of the rivulet be turned off on one side, and the pool pumped out so that the form of the little heap of accumulated sand remain uninjured, the observer will be enabled to study it. Let him now carefully divide the heap perpendicularly with a sharp spade or other cutting instrument, and he will obtain a section that will enable him to examine the mode in which it has been formed. This, however, he will not in general very clearly see if the sand be of one kind and colour; but if he will throw, as the author of these pages has done, variously coloured sands, and of differently sized grains, into a rivulet which could move them onwards to the experimental pool, care being taken that one colour and kind is fairly washed down before others are thrown in, he will very readily see the inclined positions of the resulting concentric layers. If the experiment be conducted so that the water in the rivulet be increased and diminished at pleasure, thus enabling it to carry forward larger detritus at one time than at another, sometimes even rendering the waters turbid and allowing a sedimentary settlement in the pool, the observer will obtain a great variety of results, the importance of which he will speedily see.

b. The mode in which rock detritus, shoved along the bottoms of rivers by the force of their currents, and subsequently pushed into lakes or seas, is accumulated in such situations, is precisely the same in principle as

E

the accumulation of sand in the manner above noticed.
From the different magnitudes of the objects, the effects
are greatly more striking in the one case than in the
other, and the modifying causes are more apparent; yet
the principle remains the same, and layer beyond layer
is added to the larger mass in the same way as they
were added to the smaller. The stones or sands, as
the case may be, are shoved to the edges of the greater
accumulation of loose materials, where, losing the sup-
port which they had previously received from the river-
channels, they fall over and arrange themselves accord-
ing to the laws which govern bodies under such circum-
stances.

c. If an observer direct his attention to the manner
in which detritus is protruded into any great lake, such
as those of North America, Switzerland, or Northern
Italy, it will rarely happen but that he will find consi-
derable variation both in the kind and in the mode of
the deposit thus thrust by the different rivers and tor-
rents into the lake. Hitherto we have only considered
the friction of rivers on their channels, by which detri-
tus is shoved forward into still water : it is, however,
necessary to call the attention of the reader to the de-
tritus which is either held in mechanical suspension
by the agitation of the river-water, or which is in the
act of falling through it to the bottom when discharged
into the lake. Let us suppose that the accompanying
sketch (Fig. 46) represents a lake divided into two
unequal portions by the approach of the opposite
shores to each other in one place, and that an observer
is desirous of appreciating the effects produced by the
deposition of detritus brought down by the feeding-

Fig. 46.
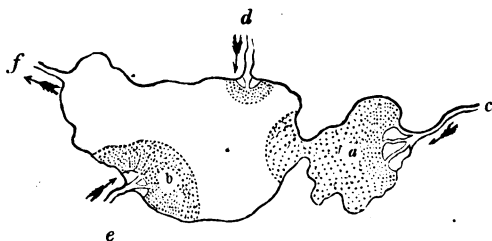
rivers, *c*, *d*, and *e*. He will in the first place take into account the velocities of the respective rivers, and this he may roughly estimate by the slopes of their respective channels, due attention being paid to the relative quantity of water in each ; he will then proceed to consider the relative permanence of given quantities of water in each river. In the case before us, let *c* be the main feeding-river, flowing from a relatively considerable distance, always pouring a considerable body of water into the lake, the surplus waters of which escape by the discharging outlet, *f*; and let *d* and *e* be the channels of two torrents which occasionally descend from mountain heights on either side of the lake with considerable force, while at other times they contain little water.

Let us further suppose that the waters of the river *c* are generally turbid, like those of the glacier waters of the Alps, though they vary considerably in quantity according to circumstances, as is usually the case with most rivers ; so that *c* has the power of transporting and pushing detritus unequally. It will be clear that the effects produced by the river *c* will be more constant than those caused by the torrents *d* and *e*, though

E 2

it may not send so great a quantity of solid matter into the lake in a given time as is done by the torrents *d* and *e*. This will however depend upon a variety of local circumstances. We will suppose, for the sake of illustration, that the collective amount of detritus thrown into the lake (Fig. 46) by the two torrents *d* and *e* is equal to that carried forward by the river *c*.

With these data before us, let us see the manner in which we may estimate the effects produced. If we were examining any given lake at present, one in which the filling process had been going on for a great length of time, we should take the present relative depths into account, particularly if desirous of forming any estimate of the time required to fill up the lake by means of the detritus now borne or thrust into it. To form, however, a clearer idea of the kind and distribution of the deposits that would be produced according to the above-noticed data, we will consider the commencement of the filling process, and, for greater simplicity, suppose the depth of the lake nearly uniform throughout, though of course the primitive form of the lake-basin would influence the products. The river *c* would accumulate the detritus it pushes along its channel by friction, in the form previously noticed, while at the same time it will pour a body of turbid water into the still waters of the lake. The force of the former is checked by the latter, and the turbid water, being heavier than that of *fresh-water* lakes, sinks in clouds towards the bottom, as may be well seen where the Rhone enters the Lake of Geneva, and in various other similar situations. The velocity with which the turbid water enters the lake carries it to various proportionate

distances; but its motion being finally checked, the sedi-
ment is deposited. As the detritus would be carried
farthest forwards in proportion to its fineness, we should
obtain complicated effects, something like those repre-
sented in the annexed section (Fig. 47), where *c* being

Fig. 47.
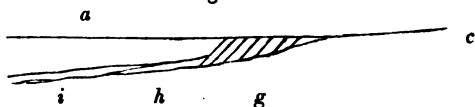
the river, and *a* the surface of the lake, *g* would be the
detritus accumulated by the pushing process; *h* and *i*,
deposits from the turbid waters checked in their motion
by the lake, the sediment being sandy at *h* and muddy
at *i*, because the larger suspended detritus would
sooner fall from the checked waters than the finer
matter. It will be obvious that, after a time, the detri-
tus, merely pushed forward, will accumulate over the
sediment thrown down from the turbid water, and that
therefore inclined beds of coarse detritus would cover
the nearly horizontal accumulations of fine sediment.
It would take up too much of our space to enter into
a detail of the complicated effects which might be pro-
duced; but many can readily be conceived.

To return to the sketch of the lake (Fig. 46). Let us
suppose, that from the complicated effects noticed above,
the general resulting mass of sediment, deposited or
pushed forward by *c*, occupies the dotted area *a*, covering
the whole of the small lake and extending a short dis-
tance into the larger lake. We have now to consider the
effects produced by the torrents, *d* and *e;* and the case
may be rendered more illustrative, if we consider that,

from the nature of the rocks traversed by the respec-
tive torrents, fragments of hard rock only are shoved
forwards by *d*, while much earthy matter and soft
rock, easily comminuted by friction, is mixed with the
harder fragments thrust into the lake by *e*. If little
earthy matter be carried forward by *d*, the accumulation
where the torrent enters the lake would form little else
than a semi-conical heap of fragments, which would
become truncated in the manner formerly noticed, as
layer accumulated above layer, and the bottom of the
lake would be little covered from this cause beyond
the heap of fragments.   With the torrent *e* the effects
would be somewhat different: we should obtain the
heap of fragments as in the other case, but it would be
mixed with softer matter, and a quantity of turbid water
would be poured into the lake, from whence there would
be a sedimentary deposit as in the case of *c*.

Thus we ultimately obtain a heap of hard, and, in
all probability, angular, fragments at *d*; a similar heap,
though mixed in a more confused manner with softer
substances, at *e*, to which is added a mass of sandy and
muddy sediment, that we may suppose, for illustration,
covers the dotted area *b*; and an accumulation of push-
ed fragments, in all probability more or less rounded, if
much rolled, and of finer sedimentary deposit, at *a*. If we
now take into consideration, that the deposits would be
greatly modified by variations in the quantity of water
in the rivers and torrents at different times, particularly
in *c*, we have a very complicated general deposit, which
would still undergo modifications as the filling process
continued ; so that eventually if the lake were filled up,
and any great geological change produced various sections

of its solid contents, there would be very little mineralo-
gical resemblances in its different parts. It must not
however be forgotten, that the greater the predomi-
nance of any one cause, the more would the general re-
sulting effects resemble each other. For instance, the
Rhone is the principal filling agent in activity in the
Lake of Geneva; and if, in imagination, we contem-
plate the whole lake filled up, sedimentary matter, de-
rived from the glacier waters of the Rhone, would be
the characteristic deposit.

d. The principle on which detritus is pushed by
rivers into the sea is the same as that on which it is
forced into fresh water; but there are several modify-
ing circumstances which the observer should be careful
to take into account when estimating the effects thus
produced. The various protrusions of deposited detrital
matter known by the general name of *deltas*, such as those
of the Nile, Indus, Ganges, &c., consist both of detri-
tus forced forward by the friction of the river-waters on
their channels, and of other detritus thrown down from
mechanical suspension in the same waters. One main
point to be taken into consideration is, that the specific
gravity of sea-water is greater than that of fresh water,
—that is, it is heavier; and hence it happens that turbid
river-water, unless it be considerably charged with me-
chanically suspended detrital matter, is still lighter
than sea-water, and will flow over it to a distance
proportionate to the velocity and volume of the river
discharging itself into the sea, all other things being
equal.

Instead, therefore, of the turbid river-waters falling
down in clouds, as happens in the case of turbid rivers

discharging themselves into fresh-water lakes, they would have a tendency to float upon the sea-waters, and to be carried, either by the current produced by the river, or by tides and other causes, to a greater distance than they would be in fresh-water lakes, however large these may be. From this cause, a more general and uniform deposit may be effected beneath the sea than beneath fresh waters, from the same quantity and quality of turbid water discharged with equal velocity into them. The observer must, however, here again take modifying circumstances into account. As far as the mere striking of a body of river-water against a still fluid is concerned, it will necessarily receive the greatest check from the heaviest or most dense; and hence any given river would be more checked by rushing into the sea than into fresh water, if it were not that in the former case it ran over it, while in the other it ran into it, and therefore received the greatest check, on the same principle that a river is more retarded by running into sands than by flowing over them.

The different density of the river from the sea water should also be attended to on another account. The greater the density of the fluid, the greater would be the difficulty of detritus of the same weight, size, and shape passing through it. Hence the same kind of detritus would take a greater length of time in passing through sea than fresh water, both being of the same depth, and therefore would be a longer time exposed to the chances of movement in the one case than in the other. It also follows, that detritus, which would just settle when the velocity of a turbid river was checked by flowing into a body of fresh water, would not so imme-

diately settle from a turbid river discharging itself into the sea. In the first place, the river would not experience the same amount of check ; and in the second, the detritus would afterwards have to pass through a denser medium to the bottom, even in the case where the river and sea waters were somewhat mixed. These hints will be sufficient to direct the attention of the observer to several modifying circumstances, and others springing from them will readily present themselves to his consideration.

An observer desirous of making direct experiments on the depth to which the turbid waters of rivers may extend, either near their embouchures, or flowing some distance out to sea, should procure water from different depths by one of those instruments contrived for such purposes, and carefully ascertain their relative specific gravities, in order that he may not attribute the presence of merely discoloured surface-water at a distance from land to a wrong cause. He should also take the temperatures of the waters at different depths, as these also may assist him in estimating the relative densities of the waters. By these means Captain Sabine came to the conclusion that the discoloured waters of the Amazons flowed over the ocean to the distance of three hundred miles from its embouchure.

e. It will be evident that if there be any great movements in the waters of the sea, they will transport a great proportion of the detrital matter, held in mechanical suspension by the rivers discharged into them, in the direction of the prevalent movement. Now there are two great movements in the waters of the sea, more particularly felt on coasts and in shallow water ; the one

caused by tides, the other by prevalent winds—by the evaporation of an inland sea communicating with the ocean, greater than the supply of water it receives from rivers, which causes a rush of water from the ocean into it —and perhaps also, to a certain modified extent, by the motion of the earth on its axis. Of the latter, commonly termed marine currents, many act in constant or nearly constant directions, while some drive part of the year in one direction, and during the other part in one directly opposed to it. The movements caused by tides for the most part act in directions opposed to each other; so that the same great body of water is moved backwards and forwards, a few hours one way and a few hours the other, local causes producing local variations both as to the relative times of the opposite movements, and in their intensity.

f. The observer should direct his attention to the various local circumstances which may influence the deposits in a delta formed in the sea, more particularly with reference to the disturbing movements above noticed, and to the exposure of the coast to the action of the waves, care being duly taken to estimate the value of the depth of sea into which the delta is protruded. If there be little movement from tides and currents, he would expect to find, under otherwise equal circumstances, that there would be a tendency to form a more muddy deposit on the margins of a delta so situated, than where tidal or other movements were brisk. Due attention should be paid to the influence of wood and small trees borne down a river, since they become entangled where the velocity of the stream is unable to keep them from doing so, and cause obstacles on which

detrital matter accumulates.   The exterior of a delta is
also greatly modified by the piling action of the waves,
when such takes place, as will be noticed in the sequel.

   g. Among so many modifying circumstances, it
would be difficult to afford the observer very direct
information as to any general character of the resulting
deposits obtained from detrital matter thus forced into
seas.   They will necessarily be more complicated in one
locality than another; inclined beds may be produced
by the friction of the rivers on their channels, which
necessarily are disposed to shift, while more horizontal
beds result from the quiet deposit of sediment from
mechanical suspension in the water.   The occurrence
of gravel or coarse sand in such deposits will necessarily
be rare in proportion to the extension of the delta,
since the general velocity of the discharged waters is
diminished according to such extension, both from the
increased line of level or nearly level channel, and
from the frequent checks offered to the onward course
of the river, which tend to split the main streams into
numerous minor branches.

   h. Attempts have been frequently made to calculate
the quantity of solid matter borne down by any given
river, either into the sea, or in some particular part of
its course.   When we narrowly examine the manner in
which the experiments have been conducted, there are
few results which can in any manner be considered as
approximating to the truth.   When we consider that
there are two processes by which detritus may travel
onwards in a river, the one pushing, the other trans-
porting by mechanical suspension, both of which fre-
quently co-exist in the same river, it will be obvious

that observations made only on the one cannot give the amount of both. The relative amount of the pushing process can scarcely be estimated except by observing the time required to fill up or occupy any given space, such as the accumulation necessary to fill up a space of given depth, breadth, and height, or the time required to advance any given delta a given distance ; the slope of the delta, and the depth of water into which it is protruded, being accurately known. Much might therefore be done at a delta, if all the matter there collected resulted from the pushing process : but as part of such accumulations is generally due to a deposit from turbid waters checked in various places, we do not obtain satisfactory results. It should be recollected that the same detritus which is held in mechanical suspension in the higher part of a river-course may fall to the bottom, from diminished velocity of the stream, in another and lower part of its course, and be then pushed onwards by friction : and this power may finally cease to act from still further diminished velocity. So that it by no means follows, if the quantity of matter mechanically suspended in a given river, in a part of its course distant from the sea, could be accurately known, that such matter was actually borne into the sea, even when there should not be any intervening lake to arrest its progress.

The usual process of estimating the quantity of earthy matter mechanically suspended in a turbid river, has been to ascertain the figure of its bed at the desired place, and its velocity, which is supposed to give the quantity of water which passed that given spot in a given time. Certain measures of the water are then

obtained, such as a cubic foot, and the quantity of sediment from it ascertained. Sometimes these measures are obtained from one or two, or even three different parts of the river; but more frequently only from one, somewhat centrical. In the first place, the laws by which a river is retarded in its course by friction are not correctly known, without which the exact quantity of water passing down a river cannot be ascertained; and in the second, we do not yet know from whence to take up given measures of the water, so that anything like an approximative mean of the detritus moving forwards in the water can be obtained.* An observer will therefore experience great difficulty in estimating the amount of detritus carried by any given river to the sea, or in given parts of its course. This, however, should not prevent him from doing the best he can with the existing knowledge on such subjects; for if he record the various precautions he may employ to guard against error, his observations may not eventually be thrown away.

i. The modifying influence of tides should be duly attended to in those situations where they flow up deltas to different distances, as is the case with that of the Ganges. The accumulating power of mangrove trees in tropical countries in similar situations should on no account be neglected, since it is frequently very considerable.

k. It can be scarcely necessary to remind the observer that all rivers do not form deltas where they flow into the sea; and that, on the contrary, some have

* For remarks on this head see " Researches in Theoretical Geology," by H. T. De la Beche, p. 68.

large wide embouchures into which tides freely flow. Local circumstances necessarily produce a great variety of effects between those observable in the open mouth of the St. Lawrence, and in the deltas of the Indus or the Ganges. The observer will find that the proportionate number of open-mouthed rivers is greatly less on the coasts of tideless or nearly tideless seas, and of great lakes, than on the shores of the ocean ; and that where large estuaries exist, the tides are strong, all other things being equal. The amount of detritus pushed forwards by friction must greatly influence the power of a river to form a delta. The quantity of detrital matter borne to the sea must greatly depend upon the kind of country which the rivers traverse ; but, all other circumstances being equal, those rivers which can push forward the heaviest and largest detritus would most readily accomplish the formation of a delta.

l. The exposure of a river's mouth to the full force of the tidal wave, if the power of the river and quantity of detritus borne down be not relatively very considerable, greatly tends to keep an estuary open. If the annexed sketch (Fig. 48) represent an estuary open to

Fig. 48.
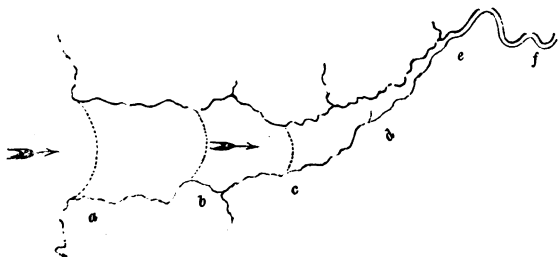
a tidal wave, then the height of the wave will be greater
at·a, where it strikes the mouth of the estuary, than in
the open sea; and it will be still higher at b, and run
with greater velocity than at a; because the same quan-
tity, or nearly the same quantity of water, is driven into
a narrower channel. It thus goes on increasing in
height and velocity until it loses the propelling power
of the water behind it, arising from the ebb of the tide
at the mouth of the estuary, and becomes checked in
velocity and lowered in height from the want of support
behind it; so that the friction on the sides and bottom
of the channel, which always retarded the waters to a
certain extent, the rise of the channel itself, and the
force of the pent-back river-waters, come forcibly into
action, and the tidal wave proceeds no farther. We
may, for the purpose of illustration, suppose that the
tidal wave increases in velocity and height in the estu-
ary represented above (Fig. 48) from a to d,—b and
c being intermediate stages,— and that from d it de-
creases by e to f, where it is finally stopped.

The observer will at once perceive that the trans-
porting power of a body of water so circumstanced
will vary considerably in different places. The turbid
waters of the river, of which the estuary forms the em-
bouchure, are necessarily discharged into this mass of
tidal waters, sometimes swept outwards, sometimes in-
wards, according to the ebb or flow of the tide. So
long as the agitation of the estuary water is sufficient to
keep it mechanically suspended, the fine detritus can-
not be deposited except in those situations where dimi-
nished agitation will permit it to fall down. It can,
however, only permanently be brought to rest in such

situations on the shores as are not exposed to the disturbing power of the breakers; and thus, unless the annual amount of accumulated mud or silt be greater than the annual amount carried off by the action of the breakers in such places, there will be no permanent increase. Hence, notwithstanding the general muddy character of the shores of estuaries, no permanent increase takes place, except under the above circumstances, or when the breakers pile up beaches on low shores, and thus render tracts of country behind secure from their ravages ; so that such tracts would be filled up by sediment, if small channels of communication were open, as frequently happens, to the height of the estuary waters.

m. The power of the river to push detritus forward necessarily receives a check proportionate to the force of the flood-tides, which may even force back such detritus by friction. As the tides vary in power, and the like happens to the river, according to the quantity of water in it, there will be a space where gravel or sand, as the case may be, is accumulated : these are frequently known by the name of *bars*, and their situation depends on a great variety of local circumstances, which an observer will take into account when he has any particular estuary or river under examination.

Much detrital matter will, however, under all circumstances be committed to the body of estuary waters. Now, although the strength of tides in such situations is sufficient to keep a great quantity of it mechanically suspended, so as to render the estuary waters highly turbid, it is clear that if a deposit did not take place somewhere, such waters would eventually acquire so

much fine detritus as to be mere mud. The observer
will find that the heads of estuaries have a tendency to
fill up, as also the sheltered places ; but that, generally
speaking, the deposits at the heads are more gravelly
and sandy than those of merely sheltered places, into
which gravel and sand are not driven by a tributary
stream. To illustrate this, let the annexed sketch

Fig. 49.

(Fig. 49) represent an estuary ; then it will generally
be found that the deposit at the head, c, is more gra-
velly or sandy, particularly in its lowest parts, than in
the merely sheltered positions, a and b. And this arises
because the detrital matter pushed forwards by the
river, d, has been arrested at c, while in the sheltered
spots, a and b, the sediment has been deposited from
the turbid waters checked in their movement, and ren-
dered more or less still according to circumstances.

Notwithstanding the deposition in the sheltered
places on the sides of estuaries, and at their heads, a
time must come, supposing a large amount of detritus
to be brought down during a series of ages, when the
sheltered spots will be filled up, and an increase take
place only at the head. The quantity of fine detritus

required to fill up the sheltered places, even supposing the increase at the head to be a constant quantity, will go somewhere, and would render the estuary waters gradually more turbid unless deposited. Now the deposit may either take place in the channel of the estuary itself, or be carried into the sea to be there distributed. The fir⁻t supposes that the velocity of the tides is insufficient to cut it up when deposited, or prevent its being deposited at all; and the second, that it can escape into the sea.

Some estuaries are so long,—such, for example, as that composed of the Bristol Channel, and its continuation up the tidal waters of the Severn,—that the *surface*-waters at their mouths, if we may use the expression, are not turbid at any time of tide, while the whole of the turbid waters are apparently driven backwards and forwards by the tides in the more inland parts. To enable turbid waters to escape seaward under such circumstances, they must necessarily have a movement in such directions. Now the mere movement of the waters in a long estuary could not produce this effect if the line of turbid water did not come, at the lowest state of the ebb-tide, outside the estuary altogether, when probably, from the general movement of the tide on the open sea-coast, a portion of such turbid water would not again be forced into the estuary, as may be well observed in short estuaries, or those where the line of turbid waters always extends into the sea at low ebb.

We have, however, to consider that the water of an ebb-tide in an estuary has all the waters of the rivers and streams, pent back by the flood-tide, added to it. Upon their relative weights or specific gravities would

depend the power of the pent-back river-waters to float upon or sink beneath the sea-waters forced into the estuary; which themselves, or at least such portions of them as are washed backwards and forwards by the tides, become brackish and increase in freshness as they approach, and become agitated with, the rivers and streams. There is, therefore, complicated action; and the inquiry ends with the power of the detritus to escape from the long estuaries seaward beneath the clearer waters above, either by the friction on the bottom of the surplus accumulated waters flowing seaward, so that the general sea-level be maintained, or from the same waters being rendered heavier by the amount of detritus mechanically suspended in them, so that they keep the bottom and remain unseen. It will be obvious that the observer may in a great measure discover how far this may be the case, by taking water from different depths in different parts of a long estuary at marked and various times of tide, and by examining their relative specific gravities and the quantities of detritus they may contain.

n. We have not space to enumerate the various modifications an estuary may sustain. It will be sufficient to notice those cases in which, at the meeting of estuary waters with the main sea, the power of the tides is unable to prevent a deposit of detrital matter where the ebb-tide of the estuary is checked by its entrance into a sea, the tidal movement of which is not prolonged in the direction of the estuary ebb, but takes a course frequently at right angles to it. When such a deposit takes place, the accumulation across the mouth of the estuary, usually termed a *bar,* is greatly assisted,

and eventually greatly modified, by the piling action of
the breakers falling on the coast generally. Let the
annexed sketch (Fig. 50) represent a line of sea-coast,

Fig. 50.
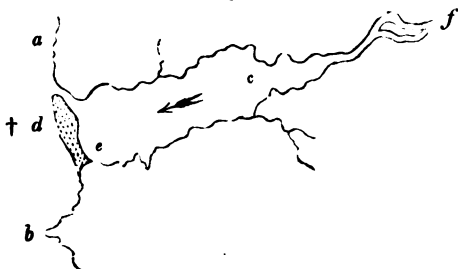
a b, from which an estuary, *c*, runs nearly at right
angles into the land, and terminates in the river, *f*, that
discharges a considerable quantity of detritus into it,
particularly during freshes or floods. Let us further
suppose that the ebb-tide has commenced in the estu-
ary, as it usually does, after the ebb has acquired con-
siderable strength along the line of coast, *a b*, and that
the latter runs in the direction of the arrow, *d ;* then
the turbid estuary waters, descending in the direction
of the arrow in the estuary, would meet the general
movement of the sea on the coast nearly at right angles,
and they would consequently receive a check where
they attained the line of coast, and a deposit, *e*, would
be gradually effected in such situation, which would be
greatly modified and assisted by the piling action of the
waves falling on the general line of coast, *a b*, as will
be noticed under the proper head. There are few rivers
which have not, from these causes, bars at their embou-

chures : they are greatly modified according to local cir-
cumstances, to which the observer must direct his atten-
tion. In some rivers the bar is so considerable as
greatly to obstruct the navigation into them, and even,
in extreme cases, may be said to close up rivers which
would otherwise possess great commercial advantages.
In the case above supposed, the estuary is necessarily
short, or one where a large proportion of the turbid
waters escape into the sea at every ebb-tide. The ob-
server should note the kind of deposits which, from the
check of the bar, take place in the estuary, as also the
kind of bottom in the sea immediately outside, or sea-
ward, which he will generally find most clayey and
muddy in the direction of the ebb-tide along the coast,
because the turbid waters, from obvious causes, there
part with the greatest part of the detritus they may
contain.

o. As the observer cannot directly view the manner
in which detritus is now deposited at the bottom of the
sea, he can only approximate towards such knowledge
by directing his attention to those circumstances which
must influence products of this description. From the
operation of geological causes, beds of clay, sands, and
the like, are indeed brought to light, and are inferred
to have been formed beneath the sea, because they
abound with the remains of marine creatures, even of
those found in the seas of the present day, and there-
fore certainly known to be such ; and thus opportuni-
ties are afforded for studying the effects produced.
This will not, it is obvious, afford an observer the
necessary data for judging of the extent to which given
marine deposits can take place, of the mode in which

they are accumulated, or of the subordinate causes
which may greatly influence them. Above all, it will
not teach him the extent to which the forces daily in
action on the surface of the globe can account for those
masses of detrital rocks, of different geological ages,
which occur in various parts of it.

p. By sounding in the usual manner with the lead,
we have direct evidence that the bottom of the sea con-
sists of mud, silt, sands, gravel, marine shells both
broken and entire, portions of corals, and the like.
Now, as from geological facts we possess evidence
that the relative positions of dry land and sea have not
been constant, but that, on the contrary, a large pro-
portion of the present dry land once constituted the
bottom of the sea, while dry land must frequently have
been submerged beneath the latter, these events having
often occurred in the same parts of the earth's surface,
we cannot be certain that the mud, sands, and gravel
found beneath the present seas were deposited there
from such seas during the existing relative positions of
sea and land, in any particular area under consideration.
It may be highly probable that the mud, silt, and the
like, found beneath the seas which bound any parti-
cular tract of dry land, may have been carried to their
present positions by those movements in the seas that
are now observable in the same situation; but to feel
assured that we do not fall in to unperceived errors on
such a subject, we must first take all the circumstances
of such sea-movements into consideration, carefully
weigh the whole of the evidence, and then see how far
such movements could carry the observed mud, silt,
sands, or gravel, as the case may be, to the localities

where they are now detected. Such observations, no doubt, require considerable care; but their geological importance is so great, that those who possess good opportunities, as often happens to naval men, should on no account neglect them. It is to the want of sufficient data on this head that we may attribute those loose generalizations so often hazarded in geological treatises and memoirs, and which, when closely examined, seem to rest on little else than the good-will and pleasure of their authors.

q. From various causes, previously noticed, detritus derived from dry land is committed to the sea. It is necessarily distributed over greater distances by the movements produced by tides and currents, than it would be if the waters of the sea were perfectly stationary. The tidal wave is only a great undulation causing little appreciable horizontal movement, except on coasts and in shallow waters, where, viewed generally and by itself, it produces a backwards and forwards horizontal motion of the same waters for a distance of about sixteen to twenty miles; local causes sometimes extending this distance, at others diminishing it. Marine currents act more extensively, and traverse the ocean in different directions; though it may be stated that a larger mass of sea-water is moved from East to West in the Equatorial regions than in any other direction in any other part of the globe. The depth to which such currents extend, when their surface velocity is known, has not been ascertained; though if we take surface causes for their origin, such as prevalent winds, the rush of water from the ocean into an inland sea, to restore the loss from evaporation, and the like, we

cannot anticipate that they will be very deep. This is a subject to which the attention of the observer is strongly invited : the only direct experiment made, that we are aware of, is that recorded by Captain Becher, who found in lat. 15° 27′ 9″ N., and in long. 17° 31′ 50″ W., that a current moving at the rate of 0·75 per hour had the same velocity at the depth of forty fathoms as on the surface.

r. When an observer is desirous of estimating the direction and extent to which detritus, derived from any particular line of coast, is drifted by movements in the sea, he should, after duly noticing the quantity and kind delivered into the sea on such line of coast, proceed to examine the direction and extent to which tidal movements may bear it, taking into account any probability of a movement sufficiently strong to shove the sands and silt forward on the bottom. In fact, he should endeavour to ascertain if the pushing process caused by the friction of the moving water, and the simple transporting action by mechanical suspension, do or do not co-exist in the streams of tide; because, if they do, the resulting deposit would necessarily be more complicated than if one only were in force. If a stream of tide were sufficiently strong, it would push detritus before it when no appreciable quantity of detrital matter was disseminated through its waters ; while, on the other hand, deposits may be effected from gently moving waters, more or less charged with such matter, which are unable to move forwards the mud, silt, and sands on the bottom. As in the case of rivers, we do not correctly know the laws which regulate the retardation of moving sea-waters by friction on the bottom

over which they pass, and therefore are unable to calcu-
late the value of such friction, when the depth of water
and surface velocity are known. Hence direct experi-
ments to clear up this subject are particularly desirable.
The observer should bear in mind, that sea-water being
heavier than fresh water, there will necessarily be a dif-
ference in the amount of retardation by friction, and
consequently of friction itself, between the two, even
when all other things are equal.

  s. Facts connected with soundings, as they are term-
ed, or those depths which are attained by a line of one
hundred or one hundred and fifty fathoms in length,
would seem to point to a certain pushing power of the
tidal movements round coasts, probably combined with
that action of waves which, as it were, shake up the
finer sediment from the bottom in minor depths, and
thus throw more detritus into the power of tidal move-
ments than they would otherwise possess. In many in-
stances also, marine currents, arising from other causes,
may assist in producing the effects about to be noticed.
It is generally found that the seaward edge of those
tracts of bottom, commonly known by the name of
soundings, shelve suddenly outwards; that is, after
sloping very gradually from the coast to the above-men-
tioned depths, they plunge at a far more considerable
angle seaward.   Let the line *a a*, in the accompanying
and greatly exaggerated section (Fig. 51), represent

Fig. 51.
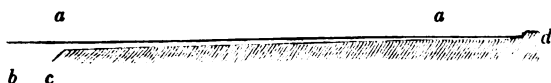
the surface of the sea, and the inclined line beneath it that of soundings extending from the coast, *d*, to the deep sea, *b*. Then it will be generally found that, after continuing gradually to deepen, the soundings will more suddenly plunge at *c*, where we suppose a depth of about one hundred fathoms, into deep water. In these cases, which are well shown on the outer verge of soundings connecting France with Norway, and including the British Islands, where the line of two hundred fathoms is but a short distance outside that of one hundred fathoms,* there is much to remind us of the form in which detritus is arranged in some deltas, if we make a section along their length. The supposition that tidal movements can produce this form at considerable distances from the land may, at first sight, appear inconsistent with the relatively small backwards and forwards motion noticed above. This difficulty seems, however, more apparent than real. Let *a b*, in the annexed section (Fig. 52), represent the surface of a por-

Fig. 52.
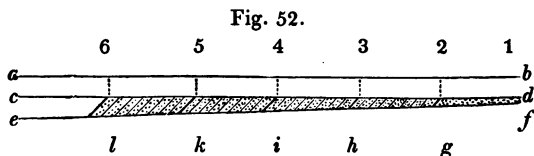
tion of sea exposed to tidal movement, so that the point 1 moves to the point 2, 2 to 3, 3 to 4, and soon, during the ebb tides, and the respective points move back to their respective places during the flood; so that, in fact, there is a to and fro movement of the whole, to the

* See the chart and remarks in " Researches in Theoretical Geology," p. 190.

amount of the distance from 1 to 2, 2 to 3, &c. There
would be modifying circumstances, to be noticed here-
after; but, for greater simplicity, we will now neglect
them. Let the line $c\,d$ be the depth to which the
tidal movement has the power to shove superficial
and given kinds of sand, silt, mud, or the like, back-
wards and forwards; and let $e\,f$ represent a bottom of
solid rock sloping from the land to the depths of the
ocean. If we now suppose detrital matter deposited
and to a certain extent levelled from f to g, any addi-
tional quantity would be thrown over at g, by the to
and fro movement of the portion of water, comprised
between 1 and 2, to the space 2, 3, which in its turn
moves in a similar manner to the space 3, 4; and so
on. The given detrital matter brought over the steep
slope g could not be again moved back to f; for it
would not only be beneath the line of shoving power
$c\,d$, but it would also require a power sufficient to push
it up the steep slope g,—one which, under the circum-
stances enumerated, could not exist. Hence, if detrital
matter, capable of being pushed about by the tidal
movement, at the depth $c\,d$, be constantly added on
the side $d\,f$ (that of the land), the same forces will
continue to level the upper part to a certain extent, ac-
cumulations of shelving beds being added to the sea-
ward steep slope, which will go on advancing in the di-
rection h, i, k, l, and be more slow in such advance in
proportion to the increased depth of the water.

This explanation is merely thrown out as a hint to
the observer, who has to consider that the movements
of a stream of tide are greater in proportion to the prox-
imity of land, from the resistance opposed to the tidal

F 2

wave under such circumstances, and therefore that the distances 1, 2, 3, 4, 5, 6, would not be equal, but decrease seawards, or from 1 to 6 ; as also that the line of soundings is not horizontal, but inclined at a very small angle ; and that the whole deposit may be greatly modified by the accumulation of fragments of shells, corals, fish-bones, &c. over fine detrital matter ; thus preserving it from that movement which could just disturb 'it. Many other modifying circumstances will also strike him, if he direct his attention to this subject, which has been more especially introduced to see how far a series of somewhat highly inclined shelving beds of sand or silt, such as are represented in the annexed section (Fig. 53),

Fig. 53.

may in this way be produced ; and, consequently, how far the accumulation of soundings, supposed to be in progress in the present day, may account for sandstone and schistose beds so arranged, that, if we are to suppose them to have been deposited horizontally above each other at the bottom of the sea, we must also suppose one of far greater depth than, in all probability, now exists in any part of the ocean, or which we should conceive ever has existed.

t. Deposits from marine currents, in which detrital matter is disseminated, would necessarily be more extensive than those from tidal streams, if detritus were discharged into them to an equal extent, since they flow over far greater surfaces. We might hazard some conjecture as to the distance to which mud or silt would travel

by such means, if experiments were made on the time it took for fine disseminated detritus of different kinds to settle at the bottom of *sea-water* a yard or any other convenient measure in depth, and also knew the depth to which a given current, moving with an ascertained velocity, extended ; but, unfortunately, respecting all these essential data we are as yet uninformed.   While on this subject, it may not be without interest to consider how far the increased density of water, in the lower parts of the deep ocean, from superincumbent pressure, would retard the fall of the finest detritus, supposing such to be brought to, and deposited from, marine currents in such situations.   To ascertain how far detrital matter may be contained in marine currents, in various parts of their course and at various depths, not only the proper instruments for taking water up from the required situations are necessary, but also such opportunities as the naval man can almost exclusively possess, and these not frequently.   Water which may be thus procured should be carefully bottled, and sufficient quantities should be obtained to detect the small amount of detritus which probably will alone be found in it.

VII. *Accumulation of detritus on coasts by means of breakers.*—*a.* On those parts of coasts which are nearly on a level with the sea when tideless, or which rise little, if at all, above high-water in tidal seas, the observer will find that there is a tendency to force shingles and sands on shore, long lines of shingle-beaches or sandy dunes being accumulated in front of level tracts of country so situated.   Such beaches or sandy dunes not only protect lowlands from the inroads of the sea, but frequently modify the lowlands themselves, either

by preventing the minor drainage of the country, which thus readily forms into marshes, or are the cause, if composed of sand, of great inroads of such sand, which is blown over the neighbouring districts ; whole bodies of it even advancing at a slow but certain rate, as is well seen in the line of sandy dunes extending from the mouth of the Garonne to the district of Bayonne.   Let the annexed sketch (Fig. 54) represent a tract of low

Fig. 54.
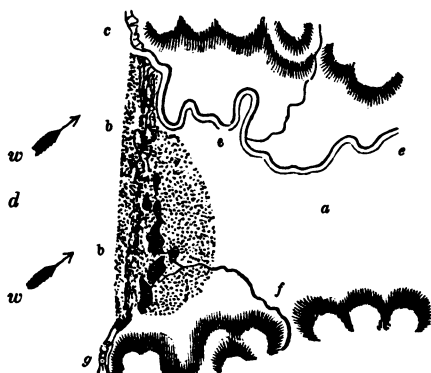
level land, *a*, bounded seaward by a shingle or sandy beach, *b b*, which protects it from the ravages of the sea, *d ;* and let *e e* be a river which delivers itself into the sea between the cliff *c* and the beach *b*, while *f* is a minor stream unable to pierce through the beach *b b*, and therefore loses itself in pools and marshes behind it, partly percolating through the beach, and partly soaking and rendering the ground marshy towards the river *e e*.

The observer, if placed in such a situation, which we

have supposed, for more easy illustration, to be com-
prised within a somewhat limited area, should endeavour
to discover the manner in which the beach itself is pro-
duced. As beaches travel in the direction of the pre-
valent winds, he should ascertain the kind of pebbles,
if it be a shingle-beach, composing the one before him.
If he find them such that they are evidently rounded
fragments of rocks derived from the cliff g, and others
in the same direction, he will conclude that they have
been brought from thence by the small oblique action
given to waves by prevalent winds striking the coast
in a similar direction. In the sketch before us (Fig.
54), these winds might strike the line of coast in the
direction of the arrows, w, w. If this were the case, the
drift would continue towards the cliff, c, and would only
be prevented from reaching it by the force of the river,
e e, which is supposed strong enough to drive the accu-
mulating pebbles outwards. It will be obvious, if this
were the state of things in the above situation, that the
area, a, may not only have been exposed to many
changes during the production of the beach, b b, but
may still continue to be so. As all areas so circum-
stanced vary according to local conditions, the observer
should direct his attention to such conditions, carefully
estimating which may have most influenced the present
conditions of the particular area examined.

The chief geological value of observations of this
kind is to see how far they may be found to illustrate
those alternations of marine, estuary, and fresh-water
deposits, often found, particularly among the supracre-
taceous or tertiary rocks. The observer should endea-
vour to obtain sections of such flat lands, which may

often be seen in deep drainage cuts; and he should collect organic remains, if he can, (in the manner noticed in the sequel,) from any beds of gravel, clay, or sand which may be thus exposed.

With regard to the deposit of detrital matter in such situations, much would depend upon the power of the river, *e e*, to keep a passage open into the sea: if a heavy gale of wind, acting on shore, force up a bank against it, the river would overflow the lowlands; and if charged with detrital matter, some part of it might be deposited on them. The minor stream, *f*, would constantly add detrital matter brought down by it to those places where it loses both its pushing power and transporting velocity, and might be the cause of a great mixture of vegetable substances, grown in the ponds and marshes, with sands, silt, and mud.

b. When sands are blown from sandy dunes inland, as commonly happens, the observer should endeavour to ascertain the amount of land thus covered, (and it is often considerable,) the rate of advance, and the general thickness and character of the resulting deposit; noting alternations of vegetable matter that mark the various surfaces which, for a time, were sufficiently stable for the growth of plants, and which became respectively covered by the sand-drift.

c. Sand-drifts are not always confined to those low tracts of land between which and the sea there are dunes affording the necessary dry sand. Sand-drifts sometimes take place at the bottom of deep bays, exposed to heavy waves rolling over shallow sandy depths before they reach the coast. The observer will find several examples of this fact on the coasts of Cornwall and

Devon. The sands in such cases are very frequently little else than comminuted sea-shells. The resulting deposits are geologically interesting, particularly as land-shells and the bones of land-animals are often over-whelmed by new drifts. The sections also are inte-

Fig. 55.
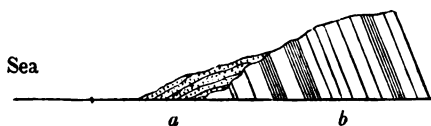
resting, being sometimes such as above (Fig. 55); *a* being the drift-sand, and *b* the rock of the hill against which it is drifted.

VIII. *Chemical deposits from fresh and sea waters.* —As waters from springs are not pure, but contain various substances in solution, and as these are the chief sources whence rivers are supplied under ordinary circumstances, it follows that in large rivers into which many tributaries deliver themselves, and in lakes, there may be numerous substances in solution, which, when mingled together, may have a tendency to act upon each other and produce new and insoluble compounds.

a. When an observer suspects that calcareous or other substances are thrown down from waters in which they were previously held in solution by the necessary quantity of carbonic acid or other substances, as the case may be, he should carefully obtain water from the rivers or lakes under his examination, and see if such substances are really present in their waters. If he be unable to analyze it himself, he should put the water into a clean bottle, immediately seal it up carefully and

F 5

tight, and forward it to some experienced chemist for examination.

b. It would be highly desirable to ascertain the approximative amount, as well as kind of substances, held in solution by the waters entering different lakes, and then obtain those of the waters at the discharging outlets, in order to estimate the kind and amount of chemical deposits, if any, which may take place in such lakes. If these latter be shallow and extensive, evaporation alone might cause appreciable effects, particularly in warm latitudes. If calcareous matter be considered to be left in the waters of the lake, due regard should be paid to its probable consumption by the shelled molluscs inhabiting it, and also to the accumulations that may thence arise.

c. Observers would gradually accumulate a large amount of valuable information on this subject, if, when unable to analyze waters themselves, they collected with the necessary care, for examination by proper persons, those of various rivers which discharge themselves into the sea. If this were done for any particular line of coast, not neglecting the minor streams, which, collectively, are as important as the larger rivers, we might obtain an approximative knowledge of the general amount of the substances, as also of their relative kinds and proportions, thus transferred annually from the dry land so drained into the sea. It would be highly interesting to know, if it be only approximatively, the amount and kind of matter thus thrown in a state of solution into the seas which surround the British Islands.

d. It may be very true that various rocks, supposed

to have been formed chemically beneath the waters of
the sea, may have been really so produced; but it re-
mains to be seen whether we must not employ the term
sea in a more enlarged sense than is usually done by
geologists. At present it seems to be supposed that
the saline contents of the sea have always been such as
are now discovered in the waters of the ocean. This
may be true also, though there are reasons which may
lead us to a contrary opinion ; but neglecting these for
the present, it, may be observed as a curious fact, that
hitherto no direct experiments have been made to dis-
cover under what conditions calcareous or other depo-
sits, resembling those of known rocks, can be produced
in *sea-water*. The line of research will readily present
itself to those possessed of competent chemical know-
ledge ; and it would be highly important to ascertain the
extent to which the present saline contents of the ocean
would carry us in accounting for those large masses of
calcareous matter, which we consider to have been of
marine origin, because in them we find the remains of
shells analogous to genera, and sometimes to species,
which now exist in the sea. The presence of such
exuviæ by no means proves that the seas inhabited by
the creatures of which they constitute the remains, were
precisely the same, as respects saline contents, as those
of the present ocean; since we know that such creatures
can be brought to live in a medium which may vary
considerably in this respect. Moreover, the waters of
the Mediterranean are more saline than those of the
Atlantic ; and yet several species of molluscs are com-
mon to both. It would seem that waters may be ex-

ceedingly saline, and even contain a different propor-
tion of certain salts, as is the case with the Caspian,
and yet molluscs thrive in them.

e. As siliceous deposits take place from some thermal
springs, search should be made in the vicinity of such
springs, particularly when very hot, for the purpose of
observing how the rocks to which siliciferous waters
may have access, may be influenced by them ; the
mode in which sand may be agglutinated by these
means ; as also the time required to cover vegetables
with a sufficient coat of silica to arrest decomposition.
Experiments to ascertain the latter point would be
highly interesting ; since there exist siliceous fossil
vegetables, which would seem to show that plants may
be so speedily covered and impregnated with silica as
to stop that decay which might take place in a few
days, particularly in tropical countries.

f. The angles at which successive coatings or beds
of substances, analogous to those of rocks, have been
deposited either from natural or artificial solutions,
should receive attention ; since they may afford us infor-
mation as to those we may allow for original deposition,
and for disturbance after deposition, when the disloca-
tions and fractures of any particular country are under
examination.

   IX. *Manner in which organic remains may be
entombed in rocks now forming.* — If the distribution
of animal and vegetable life over the face of the globe
be important to the study of organic remains generally,
the mode in which the exuviæ of such animal and
vegetable life may be now entombed is not less so.

   a. There can be scarcely any one who has seen sec-

tions of ground laid open for roads, ditches, or other
purposes, who has not observed that the shells of the
common snail and other land-molluscs are often found
immediately beneath vegetation, while the bones of
reptiles, birds, or quadrupeds are exceedingly rare in
the same situations.   The rapacious and scavenger ani-
mals in general either devour the bones with the other
parts of the creatures they destroy, or eat up the bones
of dead animals which others have left, and which
rarely escape the constant search made by numerous
creatures for such offal ; consequently few bones remain
on the surface of land to be covered by the soil result-
ing from animal and vegetable decomposition, or from
earth drifted by different causes over them.   The
chances therefore are against the preservation of the
bones of animals immediately beneath terrestrial vege-
tation from ordinary natural causes.   With the solid
parts of land-molluscs, such as the common snail and
others, the case would be different, for many of these
molluscs bury and conceal themselves in holes in the
ground ; and as multitudes die in such situations, and
their fleshy parts are there consumed by various small
creatures which do not attack the shells themselves,
these latter remain to be covered up by earth washed
by rains into the holes, and eventually are for the most
part preserved entire, or nearly so, in the common
superficial soil of dry land.

    b. To estimate the manner in which the bones of
terrestrial animals may be entombed on dry land under
circumstances which may so far be considered ordinary
that the necessary conditions exist in numerous parts
of the earth's surface, the observer should direct his

attention to the accumulations of fallen fragments of
rock and other substances, which take place at the bot-
tom of open cracks and rents in rocks, at the base of
precipices, and in caverns tenanted by different crea-
tures, such as hyenas, bears, &c.   Into the open fis-
sures so common in many limestone districts, animals
frequently fall, either in consequence of being chased
by others, by unsuccessful attempts to leap over the
fissures, or in consequence of the earth giving way on
the edges by their weight.   In alpine or cold countries,
bridges of snow, stretched over fissures, frequently give
way under animals attempting to cross them, and thus
the latter are precipitated into the clefts beneath.   Into
these fissures fragments of rocks, earth, and sometimes
plants, also fall from ordinary causes, and eventually
entomb the remains of the animals, which may consist
of their bones, as entire as they were after the fall; the
fleshy parts of the creatures having been decomposed,
or devoured by such birds as could descend into the
fissure, and were unable to swallow or carry away the
larger bones.   If the fissure be in a calcareous rock,
and there be a stalagmitical deposit of carbonate of
lime, as not unfrequently happens in such situations,
there may eventually be a compact mass of fragments
of rock, bones, and calcareous cementing matter, filling
part of the fissure.   The observer, when he has any
part of a fissure apparently so filled before him, should
be careful to remove the bones with great care, in order
that, if not conversant with comparative osteology him-
self, they may be sent to an experienced comparative
anatomist in as perfect a state as possible, to decide
how far they may be the bones of animals which still

exist, or be those of species no longer discovered living
on the surface of the earth, and consequently the con-
tents of the fissure be either referred to the present
geological epoch, or to one anterior to it.

When an observer has a fissure filled in the manner
above noticed before him, he should not content him-
self by abstracting bones only from the upper, or merely
from the lower part ; for it may have so happened that
the fissure has continued open during a time in which
there has been a change in the animals inhabiting the
country ; and, consequently, if the same causes had
continued to operate, the remains of the earlier tenants
of the district would be entombed in the lower part of
the fissure, and of the later in the higher portions.
Whenever opportunities offer, the observer should note
the manner in which bones occur in the retreats of ani-
mals which carry their prey into such places in order to
devour them ;—the broken or other condition of such
bones ; and the accumulation of earth, animal fæces,
fragments of rock, &c. which may cover them.

c. Large tracts of marsh-land, interspersed with small
shallow lakes of water, would appear to be situations
highly favourable to the accumulation of vegetable ex-
uviæ.   The leaves of trees which grow in such situa-
tions, falling on the various patches of water, take a
horizontal position, forming a layer over the top of
them.   The leaves gradually soak up water, and are
readily pressed down by the accumulation of other
layers of leaves upon them, or sink from their own in-
creased specific gravity to the mud at the bottom.   An
observer should attend to the mode in which the re-
mains of vegetation are thus entombed, particularly in

tropical countries, where such accumulations sometimes take place on a large scale. He should also note the manner in which the exuviæ of aquatic creatures, frequent in such situations, become mingled with the remains of plants, as may also be the case with the bones of many terrestrial quadrupeds. He should by no means neglect to remark the manner in which the remains of animals and vegetables may be preserved in peat-bogs. These are often of considerable extent, and the facts connected with them highly interesting.

d. The fall of great quantities of ashes and cinders, discharged in some great volcanic eruption, would appear to be the cause of a greater sudden entombment of terrestrial animals and plants, with the probability of preserving their more solid parts entire, than can be obtained without the aid of moving water under other circumstances. The dust is sometimes so fine, that with the aid of moisture, which subsequently consolidates it, moulds of the internal forms of creatures may, under very favourable circumstances, be preserved, after decomposition has removed the flesh over which the dust and cinders first fell. Of this fact one or two remarkable instances have been observed at Pompeii, where moulds have been thus obtained of parts of the human form. Such cases must of necessity be exceedingly rare ; but the preservation of the osseous remains of reptiles, insects, birds, and quadrupeds, would, we should conceive, be by no means so, particularly in the vicinity of the volcanic vent whence the ashes and cinders were discharged. Plants also, we should imagine, would be abundantly entombed under similar circumstances. Observers, therefore, favourably situated,

should not neglect the search of organic remains amid beds of volcanic ashes and cinders. In Pompeii and Herculaneum they have splendid examples of cities overwhelmed by substances discharged from a volcano, in which are not only found the osseous remains of man, but also an immense variety of his works, extending even to manuscripts, that have thus been preserved from the various causes of destruction to which they would have been exposed had they not been so enveloped.

e. Although the remains of animals and plants may thus, to a certain extent, be preserved on dry land without the aid of moving water, it is to deposits produced by this agent, and to others resulting from chemical changes in bodies of water, that we must turn for the preservation of the great proportion of organic exuviæ now entombed in mineral matter. The observer, therefore, should carefully direct his attention to the diversified manner in which this may be accomplished; so that when he studies the mode in which the organic remains of former geological periods occur, he may be enabled to judge of any difference or resemblance he may discover between them.

When treating of mechanical and chemical deposits effected in lakes and seas, or resulting from temporary floods over land commonly dry, we abstained from noticing that the greater part of such products contain the remains of animals and plants which have, from various causes, been enveloped by them. The fish, molluscs, and other inhabitants of a river, are, under ordinary circumstances, so adjusted to its velocity, volume of water, kind of bottom, and the like, that we can look to little

else than their natural death, which probably is rare, for the preservation of their remains in the mud, silt, sand, or gravel which may happen to accumulate in any particular part of such river. The solid parts of fluviatile molluscs are, perhaps, the only remains of creatures, constantly living in the river itself, likely to be enveloped by detritus thrown down in any part of its course. As, however, numerous rivers cut away their banks, when the latter are not protected by human ingenuity, the observer should direct his attention to the relative amount and kind of animal and vegetable remains that may be thus derived, and subsequently deposited in accumulations of mud, sand, or gravel formed by the river. He should not neglect the power of large trees washed out of the river-banks—as often happens in districts in their natural condition, unmodified by man—to alter the course of the river itself, particularly in level countries; and thus cause accumulations of detrital matter, mingled with organic remains, in such particular situations.

f. The fish in rivers, during floods, being exposed to a greater volume of water moving with increased velocity, seek shelter in situations where diminished velocity, caused by the friction of the water on the bottom and sides, enables them to retain their places. Fluviatile molluscs generally inhabit localities that are secure from the ravages of common floods; but when extraordinary floods sweep down the channel of a river, and leave accumulations of detritus in different situations, an observer would do well to examine such accumulations, and note the manner in which the shells of fluviatile molluscs may be enveloped by the detritus.

During river-floods which may be considered of extra-
ordinary magnitude, numerous terrestrial animals and
plants are borne onwards, and are not unfrequently left
in those situations where the waters spread over flats
and low grounds.   An observer should endeavour to
ascertain, when the waters have subsided, how far any
animal and vegetable remains thus, as it were, cast on
one side may become enveloped by sedimentary matter,
and how far they would remain exposed to the ordinary
chances of decomposition, from atmospherical causes,
when uncovered by such matter.

g. The relative amount of organic exuviæ which may
be entombed in mud, silt, sand, or gravel, by rivers in
their courses, either under ordinary or extraordinary
circumstances, is perhaps not great; though, from the
change in the river-courses of some countries, more may
be eventually accomplished in this manner than may
at first sight appear probable.   With respect to accu-
mulations of organic remains among the detritus depo-
sited at their embouchures, either in lakes or seas, the
case is different.

The greater part of those sedimentary deposits which
have been previously noticed as taking place in such
situations, not only contain the remains of fluviatile
and terrestrial creatures washed down the rivers and
brought to rest, according to their relative specific gra-
vities and other circumstances, but also the exuviæ of
various creatures which live in the higher parts of the
sedimentary deposits themselves, and which are either
lacustrine, estuary, or marine, as the case may be.   Un-
der ordinary circumstances, many molluscs die naturally,
and leave their solid parts entombed at various depths,

according to their respective habits, in the higher parts, for the time, of the accumulated detritus ; or are killed by hunting-molluscs, which, after piercing their shells and sucking their juices, leave the solid parts or shells of their prey in the mud or sand, which eventually become still more deeply entombed by the subsequent accumulation of additional detritus.

The observer should attend to the various modes in which the remains of animals may thus be buried in mineral matter, carefully weighing those circumstances which may produce mixtures or alternations of terrestrial, fluviatile, estuary, and marine remains by the mere transport of organic and inorganic matter into given situations. He should recollect that the dead bodies of creatures borne downwards by rivers into lakes or seas may possess different specific gravities, and therefore would be brought to rest according to their state of decomposition at the time, and various other obvious circumstances ; that mere bones and shells, unless the latter be so washed away from dry places that they float, would sooner be deposited, under the necessary conditions, than dead animals with their flesh upon them ;—that plants or portions of trees would float or sink at unequal depths, according to their relative specific gravities at the time ; and that they may be drifted greater or less distances, according to circumstances. In the case of, succulent plants, ferns, leaves of trees, and the like, he should mark the length of time and the conditions during or under which they can remain longest uninjured, and the mode in which they may be entangled on the skirts of a delta, the banks of an estuary, and other situations ; noting

the different amount of succulent plants, ferns, leaves of trees, and the like, which may be accumulated among the roots of mangrove-trees in the tropics, or by other means in the colder regions of the globe. The observer should carefully estimate, from the facts he discovers, the various probable mixtures of organic substances with detrital matter in any delta or river embouchure he may study, weighing well the influence of any particular condition or conditions which may appear to modify the general product.

Sections occasionally present themselves in deltas when the waters are low, or when portions are raised by earthquakes. These should be carefully examined; and the mode in which organic exuviæ occur, if such are discovered, should be noted. An observer should endeavour to trace whether any organic substances he may discover in such situations have been quietly covered up, pushed forward by the river-waters, or brought to rest in a more sudden and violent manner; which last state is generally marked by a very irregular mixture of all the substances of which the particular deposit is composed.

Extraordinary causes, or floods, can scarcely do otherwise than produce a different kind of accumulation, at the entrances of rivers into lakes or seas, both of organic and inorganic substances, than ordinary causes. When, therefore, sections can be obtained under favourable circumstances, an observer should endeavour to ascertain the different effects produced by this difference in causes; recollecting that organic remains would probably occur in a different manner in one case than in the other, not only as regards their position in the detrital

deposit generally, but also with respect to the relative proportions of the various kinds of animals and plants entombed.

h. Organic remains are most probably enveloped by detritus of various kinds at the bottoms of lakes and seas under circumstances somewhat different from the preceding. The effects above noticed necessarily occur at the junction of lines of rivers with those of coasts; and if there were no antagonist forces in action, the various coast-accumulations of detritus, and of organic exuviæ mingled with them, would tend to form such constant additions to the superficies of dry land, that the areas of lakes and seas would as constantly diminish. Waves breaking against coasts tend, as has been previously seen, to wear them away under certain conditions, while under others they throw detritus from the sea upon the land. Breakers not only eject sand and pebbles, but also molluscs, fish, corals, and other organic substances, under favourable circumstances, upon coasts, where, accumulation succeeding accumulation, a mass of rejectamenta, varying according to local conditions, may be eventually formed. The observer should note the circumstances under which organic remains may be thus enveloped, carefully weighing the modifications which may be produced by local causes in such accumulations. It will be obvious that the surface of water exposed generally in lakes is not sufficiently extensive to permit that nearly constant supply of breakers which, under otherwise equal conditions, would heap considerable quantities of detritus and organic exuviæ on a sea-cost. Waves are indeed more easily produced, other things being equal, on the sur-

face of fresh-water lakes than on that of the sea by a given force of wind, because the liquid acted on in the one case is specifically lighter than that in the other : but then the waves of lakes, when equal in size, do not fall with the same weight as breakers on sea-coasts. Detritus being, however, thrown on the shores of lakes by breakers under favourable circumstances, an observer should examine any sections he can obtain of such accumulations, in order to mark the extent to which organic remains may be included among them.

i. We should anticipate, that in proportion to increased distance from the coast, accompanied by greater depth of water, and the consequent greater tranquillity which would prevail in the lower parts of a lake, there would be a more extensive and more uniform deposit over such organic exuviæ as may be there collected, than on the immediate coasts ; and that these organic remains would commonly consist of the parts of creatures which generally inhabit the lower parts of the lake, mingled with the exuviæ of terrestrial animals that have perished in their attempts to cross from coast to coast, or have been carried far into the lake by river-floods. Probably also water-logged wood and the leaves of plants might be accumulated in the same situations.—As these deposits beneath the waters of lakes cannot be seen while forming, an observer can only approximate towards a knowledge of their mode of accumulation by carefully noting the conditions existing in any lake under examination, not only as regards the discharge of detrital matter into it, but also the envelopement of organic exuviæ by such detrital matter. It will be obvious that the conditions will not be

equal in deep and in shallow lakes: creatures which may merely fringe the shores of the former, may cover the whole bottom of the latter; and waves which would not disturb a deposit at the bottom of the one, would move detritus upon that of the other.

k. The foregoing observations in some measure apply to deposits enveloping organic remains beneath the sea at a distance from the coasts. In this case, also, an observer can only approximate towards a knowledge of the effects produced, by carefully noting those circumstances which may directly or indirectly influence them. Allowances must in like manner be made for shallow and deep seas, and the consequent modifications in the accumulations of detritus and organic remains formed in them. In lakes, whether formed of saline or fresh water, the superficies is not in general sufficiently extensive to come within the influence of any great variety of climate; and therefore the distribution of the fish, molluscs, and other creatures living in them, is not likely to be greatly modified by this cause. With the inhabitants of the sea, the case is altogether different: climate, though by no means the only modifying cause, does considerably influence their distribution.

l. We must refer to the works which treat of the distribution of animal and vegetable life over the surface of the earth for information on that head: it will be enough to state, that multiplied observations on this subject have shown that the same species are not necessarily discovered in any two given localities because the latter are alike as to climate and other conditions; but, on the contrary, if all animals and vegetables now existing on the face of the globe were suddenly to be

enveloped in a continuous bed of rock, that there would be little resemblance in the organic contents of the various parts at the distance of a few hundred miles from each other : consequently, though contemporaneous deposits of mud, silt, and sand are now taking place, and enveloping organic exuviæ around the British Islands and on the coasts of China, such deposits could not be proved to be contemporaneous by the organic exuviæ contained in each.   Neither would any percentage of molluscs found in the deposits, and now existing in their respective neighbouring seas, prove their contemporaneous origin, though to classifications of rocks founded on this circumstance great importance has lately been attached, unless it can also be proved that the shores of the British Islands and those of China have been contemporaneously exposed to exactly the same conditions,—a circumstance that does not appear very probable.

  m. An observer can make direct observations on the kind of bottom found beneath the sea, in those depths termed soundings, by means of the common lead employed for such purposes ; and on the animal and vegetable life, at small depths beneath the immediate bottom, on the bottom itself, and in the sea, by dredging and fishing. Observations of this kind might be made more instructive than they have hitherto been to the geologist, if charts were constructed, not only exhibiting the depth and kind of bottom on given coasts, but also the force and direction of tides and currents which could transport detritus, the kind of detritus thus transported, and the parts of the sub-marine area tenanted by particular portions of animal and vegetable

G

life.   By thus speaking, as it were, to the eye, more
general and definite ideas are obtained than by pages of
description.   The scale of such charts would necessarily
depend upon the amount of generalization attempted ;
but we can readily conceive that much general informa-
tion might be conveyed upon a scale of one inch to the
mile, that of the Ordnance Maps of Great Britain.

n. With regard to the mineralization of organic re-
mains in various rocks—that is, the frequent change of
the original matter of which the organic substance itself
was composed when enveloped in mud, silt, or sand, as
the case may be, into that of which it is often com-
posed in rocks—we can readily imagine a series of expe-
riments to be so conducted, though the great element,
time, may be wanting, that much information may be
obtained on this head.   Suppose that an observer is
desirous of forming some estimate of the value that
should be attached to the percolation of water, charged
with carbonic acid, through mud, silt, or sand, upon
different organic remains contained in them, we imagine
that he can do so by procuring a large vessel or box, of
any dimensions or materials that may be considered
most convenient, divided upon the principle sketched
in the annexed cut (Fig. 56), which is supposed to

Fig. 56.
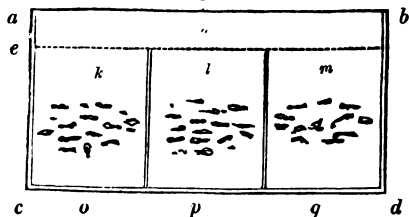
afford a vertical section of such a vessel or box, *a c d b.*
Let this be divided into four compartments, of which
three, *o p q,* are equal to each other and open at top,
while the fourth, *h,* extends over them horizontally and
is open at bottom.   Let the compartments *o p q* be now
respectively filled with mud, silt, and sand, of chemical
compositions considered most convenient for the experi-
ment, up to the line *e f,* and organic exuviæ, such as
shells, fish bones, saurian bones, and the like, be placed
in the mud at *k,* the silt at *l,* and the sands at *m,*
taking care that such exuviæ be as much as possible
of the same kinds, and placed in exactly the same rela-
tive situations in each compartment.   If water charged
with carbonic acid be now introduced into the compart-
ment *h,* so as to fill it, it will tend to percolate through
the substances in the compartments *o p q,* provided
their respective bottoms be constructed of porous mate-
rials, as is necessary. In percolating downwards through
the respective compartments filled with mud, silt, or
sand, the carbonated waters will pass the organic ex-
uviæ, *k l m,* and produce effects upon them according
to their respective chemical compositions.   If the ves-
sel *h* be constantly supplied with water charged with
carbonic acid in proportion as it percolates through the
compartments *o p q,* and the experiment be continued
a given time, such as a year, the condition of the or-
ganic exuviæ in each situation will show the amount of
change that has taken place from the percolation of the
carbonated waters.   Of course the chemical composi-
tion of the mud, silt, and sands should be known pre-
vious to the experiment, in order that no sources of

error may arise from the action of the carbonated waters
upon these substances.

It will be obvious that these experiments may be
greatly varied, care being always taken to produce such
effects as we may conceive to take place in nature ; and
that a great diversity of apparatus may be contrived for
the purpose.   We may even attempt to replace by
other substances such parts of organic exuviæ as may
be removed by the action of the solutions employed to
percolate through mud, silt, or sands.   With care we
may, perhaps, obtain the complete removal of the car-
bonate of lime of shells by such means, such as has
often been accomplished in natural processes, and suc-
ceed in introducing other substances, such as silica, into
the resulting cavity.   These and other experiments to
illustrate natural processes by artificial means belong to
what may be termed 'Experimental Geology,'—a branch
of the science which has not hitherto received that gene-
ral attention which its importance demands.

ℴ. The principal mineral substance composing rocks
which contain organic remains and are referred to a che-
mical origin, is limestone.   In general, organic exuviæ
are well preserved in calcareous deposits, which can be
observed to take place in various situations where waters
highly impregnated with carbonic acid lose that acid,
and the carbonate of lime, previously held in solution
by the aid of the carbonic acid, is thrown down upon
any substance it may encounter.   Organic substances
are thus enveloped and preserved in calcareous matter,
possessing various degrees of hardness and solidity, ac-
cording to modifying circumstances. Petrifying springs,
as they are termed, are known to every one.   The sub-

stances placed beneath them are merely encrusted by the deposition of earthy matter, usually carbonate of lime, either by the loss of the substance from the water which held them in solution, or by the evaporation of the water altogether. An observer will readily perceive that such springs commonly collect together numerous plants, land-shells, bones and stones, which thus become cemented into a constantly increasing mass. He should direct his attention to those situations where ponds or small lakes are formed of carbonated waters, holding carbonate of lime in solution, and observe the mode in which organic remains often become enveloped by a calcareous deposit. The courses of running waters also will be found covered by calcareous deposits under the necessary conditions. When such deposits of calcareous matter, commonly termed Travertin or Travertino, are before him, an observer should endeavour to estimate their geological value, by noting the organic exuviæ they contain, their extent, depth, general character, and relative importance as portions of mineral matter forming a component part of the district.

p. Other substances, such as silica and sulphate of lime, are thrown down from mineral springs, as they are termed, in some situations : the mode in which they envelope animal and vegetable remains, their relative importance, and the conditions under which the resulting deposits are produced, should be carefully noted.

q. It is inferred that limestones are now forming extensively beneath the sea in many situations, and there envelope organic remains. Direct evidence on this subject cannot well be obtained, further than by

seeing if carbonate of lime be thrown down from sea-
water, and envelope such exuviæ of animals and plants
as it may encounter.   Hitherto the evidence on this
head has been extremely scanty ; but marine shells and
corals have been obtained which were cemented by
compact calcareous matter, apparently the product of
the present geological period ; and stones and sand
have been stated to have been taken from beneath sea-
water, which were agglutinated by carbonate of lime, now
forming in the same situations.   If the saline contents
of the sea be the same now that they were during the
time when many calcareous deposits, full of marine
shells, &c., were effected beneath the seas of former
geological periods, we can see no reason, *à priori*, why
similar deposits should not now be in progress.   An
observer should take into account the various conditions
necessary to produce a calcareous deposit beneath the
waters of the sea, containing the saline substances they
now do, coupling it with the existence of creatures, the
more solid remains of which may be subsequently en-
tombed in the same situations.

    r. Coral reefs have been considered by some to be
extensive ; that is, to cover a considerable submarine
area with a broad sheet of calcareous matter, formed of
the hard parts of saxigenous polypi, cementing shells
and other hard parts of marine creatures.   Others again
consider, that they do not uninterruptedly cover exten-
sive areas, but occur in isolated patches on the summits
of submarine mountains, or in lines skirting coasts.
No class of observers can possess such opportunities of
studying the various conditions under which coral reefs

and banks exist as naval men, or of collecting data as to the depth at which certain species of coral descend in the water, the extent of such reefs, and the like. It would be desirable, if an observer be unable to distinguish the different species of corals himself, to grapple up specimens from different depths on the skirts of a coral reef, carefully put them away in some soft substance, so that the finer portions remain uninjured, with labels as to depth and situation whence they were taken, in order that they may be eventually submitted to the examination of experienced naturalists.

X. *Volcanos.*—From the striking character of volcanic phenomena, there are few persons who, being near a volcano at a time of eruption, have not to a certain extent become observers of such phenomena. In general, however, the observations made are of little value, with the exception of those recorded by a few scientific individuals, from the want of attention to those facts which more particularly deserve notice, and which lead to a right understanding of the cause of volcanic action.

a. An observer should in the first place attend to the situation of the volcano ; not confining himself to the mere mountain itself, but taking in as much of the surrounding country as circumstances will permit. If the volcano be situated in a district composed of non-volcanic rocks, great attention should be paid to the position of the beds of such rocks, if they be stratified ; noting whether or not they dip away from the volcano as a centre, or take other positions. Above all, it is necessary to sink the importance of the volcano itself, whatever may be its magnitude, in that of the district generally ; by no

means allowing the splendour of the eruptions, and the personal danger frequently attending observations at such times, to interfere with a correct estimate of its relative size as a part of the earth's surface.

There is no better mode of reducing the undue importance an observer may attach to a single volcano, than by constructing a strictly proportional section of the country in which it may occur, the perpendicular heights and horizontal distances being on the same scale. If *a* (Fig. 57) represent the section of a volcano

Fig. 57.
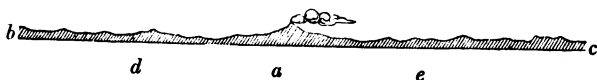
five thousand two hundred feet high; the line *b c*, a portion of country twenty-five miles in length; and *d e*, mountains about two thousand five hundred feet in height; it will be seen that, if we prolong the line, *b c*, about twenty-five miles on both sides, the volcano would soon lose that relative importance which has been purposely here given to it, by making it double the height of mountains on either side.

When instead of a single volcano an observer discovers a group of several, he should still keep in view their importance relatively to some given district, until finally he may, as in Iceland, find the whole country composed of little else than volcanic products. By these means he will not over-estimate the value of any given volcano or group of volcanos; neither will he, by thus classifying their relative importance, undervalue any volcanic district he may examine.

b. It has been much disputed of late whether, before
a volcano came into activity in a district, the rocks
composing the latter were or were not thrust upwards
around the place where gaseous, liquid, and solid pro-
ducts were subsequently ejected.   To the locality con-
sidered to have been raised and fractured by forces act-
ing upon pre-existing rocks from beneath, more at one
point than at others, the name of ' craters of elevation'
have been given, to distinguish them from ' craters of
eruption', considered to have been afterwards produced
by the well-known ejection of ashes, cinders, and lava,
which form a conical heap, with a funnel-shaped cavity
towards the apex, kept open by the force with which
the elastic vapours and gases escape upwards ; thus
driving ashes, cinders, and lava before them.   Craters
of eruption are again considered by other geologists to
have been mistaken for craters of elevation ; and it has
been inferred that the observed phenomena may be ex-
plained by the shifting of volcanic vents, and the action
of a volcano on the small scale in the centre of an area,
which had been previously covered by the same volcano
when in a greater state of activity, the matter necessary
to complete the conical heap, which once covered the
larger area, having been scattered during a great volcanic
eruption.

To illustrate the theory of craters of elevation, let
a b (Fig. 58) represent a rock thrust upwards by a
force, *c,* acting from beneath with such intensity as to
fracture it.   It is considered that the elastic vapours
and gases, having now a free vent upwards, would pile
up successive heaps of ashes, cinders, and lava in a
conical form, partly represented by the dotted lines

G 5

Fig. 58.
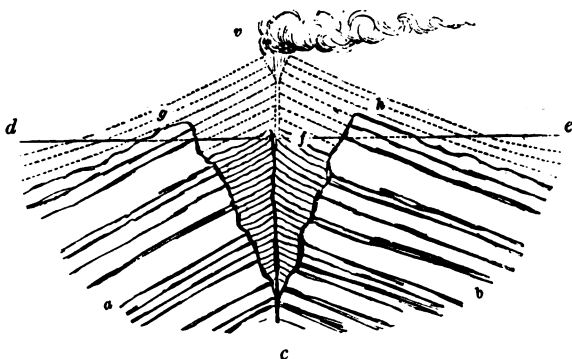
beneath *v*, and that according to the amount of such accumulated volcanic products would be the appearance of the volcano taken as a whole at any given time. For the sake of better illustration, we have here supposed the first accumulations, from eruptions of cinders and the like, to take place beneath the sea, so that at some given period there may be a volcano, *f*, existing as an island, surrounded by an amphitheatre of land, *g h*, forming another island which is circular. It will be evident that, from successive volcanic accumulations, the cavity caused by the fracture of the fundamental rock, *a b*, will be filled, and that finally it may be entirely covered over and concealed by substances discharged from the volcano. The sketch above (Fig. 58) is only one of many modifications of contorted or broken strata with which cones of eruption may be connected, and to which the name of craters of elevation may be given. To illustrate simple craters of eruption, let *a b* (Fig. 59) be a mass of rocks, pierced at *c* by a crack or other

Fig. 59.
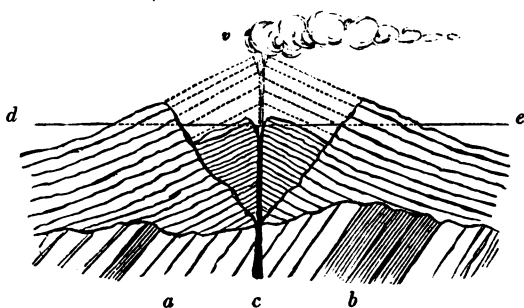
shaped rent, which has not upheaved the rocks, *a b*. Then if *d e* be the level of the sea, and ordinary volcanic eruptions take place upwards through *c*, they will gradually accumulate in successive conical layers until they attain any given altitude, such as *v*.   It is considered that if all the mass represented by the dotted lines below *v* be now removed by some great volcanic explosion, and the volcano still continue in a state of minor eruption, we might obtain a volcanic island in the centre of an amphitheatre of land.

Before we direct the attention of the observer to particular facts, we should premise that the fractured and upheaved character of the fundamental rock, *a b* (Fig. 58), may be observed in many situations both on the large and small scale among rocks which are not volcanic, and that the occurrence of rocks so situated involves no geological improbability.*

c. The observer should endeavour to ascertain whether there is evidence of strata dipping from a central part outwards in any volcanic district he may examine,

* See " Researches in Theoretical Geology," p. 211.

be such district either great or small.   Should he find
such strata, he should endeavour to trace the continuity
of the various beds, distinguishing whether or not they
are volcanic.   If formed of beds of igneous rocks, such
as trachyte, basalt, trachytic or basaltic conglomerates,
and the like, he should be particularly careful in tra-
cing them round the volcanic vent or vents ; since, if
they be completely continuous, without other change
than rocks of such characters generally suffer in mode-
rate horizontal distances, or be merely broken by ra-
vines in lines radiating from the volcanic vent or vents
as a centre, the evidence would be in favour of a crater
of elevation in such particular situation.   If the rocks
surrounding the volcanic district were not of an igneous
character, but such as are commonly referred to an
aqueous origin, and they were upturned towards the
volcanic vent or vents as a centre, the evidence would
also be in favour of a crater of elevation.

   Should an observer find a series of beds dipping out-
wards around a volcanic district, simply composed of
cinders, ashes, and the like, with here and there a body
of hard rock, such as might readily be considered the
section of a lava-current, the evidence would, as far as
it goes, be in favour of a crater of eruption ; though, as
previously shown in Fig. 58, a crater of elevation may
still be concealed beneath.   There is, however, no rea-
son, that we are aware of, why there should not be
numerous simple craters of eruption which are not based
on others of elevation, while at the same time there
should be numerous volcanic cones, produced by suc-
cessive eruptions, resting upon craters of elevation,
many of which may not be visible.   The accumulations

of ashes, cinders, and lava-currents, composing volcanic
cones, are merely piles of substances thrown out by
elastic vapours and gases at those points where such
vapours and gases find vent. It will be evident that
such vents may be as readily obtained at points along
those great lines of fracture which exist on the earth's
surface, as in situations where pre-existing beds of rocks
have suffered great flexures and contortions, some of
which have been somewhat hemispherical and fractured
in their weakest parts, those which are highest and cen-
trical. An observer should direct his attention to the
magnitude of a crateriform cavity. If very large,—such,
for instance, as that of Deception Island, New South
Shetland,* which is five miles in diameter,—the proba-
bilities are against such a crater being one of simple
eruption, while relatively small craters may readily be
referred to such an origin, in the absence of more direct
information, often wanting in islands.

We can very readily conceive the existence both of a
crater of elevation, in the centre of which there may be
a crater of eruption, and of a crater of eruption without
a trace of a crater of elevation, upon the same line of
dislocation. Let *a b*, in the annexed sketch (Fig. 60),

Fig. 60.
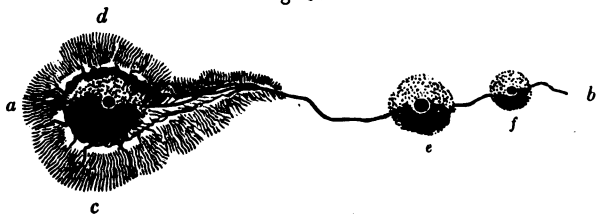
* Journal of the Geographical Society.

represent a portion of a great dislocation or fracture of
the earth's surface, such as are by no means rare in
many countries.   Let *a* be the point where the fracture
may terminate in that direction, the crack becoming a
flexure, which, denuded horizontally, produces the cir-
cular arrangement of rocks, *d a c*, or circus of elevation,
as it is often termed when its dimensions are consider-
able.   If volcanic vapours and gases, struggling to free
themselves, find vent at this point, there would probably
be a conical accumulation of ashes, cinders, and lava,
surrounded by a circular escarpment of rocks, *d a c*,
dipping outwards ; and consequently there would be a
crater of eruption in the centre of a pre-existing crater
of elevation.   Let *e* and *f* be two other points on the
same line of dislocation where volcanic vapours and
gases have forced themselves a passage, driving out
ashes, cinders, and lava, and we should have two craters
of simple eruption without any pre-existing crater of
elevation, though we can readily conceive there would
be a general tendency to bulge out pre-existing rocks in
such situations.   The observer will have no difficulty
in conceiving many other irregularities and flexures on
a great line of dislocation through which volcanic pro-
ducts might find vent; thus accumulating a heap or
heaps of ashes, and the like, in the central portions of
elevated rocks, arranged in the form of a crater, inde-
pendently of the action of volcanic power itself, which
being directed more to one point than another, might
drive superincumbent rocks upwards, and form a large
crateriform orifice, in the centre of which a conical pile
of ashes, cinders, and lava may subsequently accu-
mulate.

We would particularly advise the observer to study the probability of certain volcanos occurring in lines of dislocation, either straight or curved. The east and west line of volcanos extending across Mexico, and including the modern and suddenly developed volcano of Jorullo, has often been considered a great dislocation of the earth's surface, through which volcanic matter has been ejected at several points of least resistance.

d. The observer should direct his attention to the magnitude of a volcano, as compared with the violence of the eruptions from it. Volcanic eruptions are evidently of different degrees of intensity; but we can readily conceive that a given intensity, produced by any given conditions, may be modified and checked by alterations in those conditions; so that the maximum intensity of the eruptions from a volcano, in the early periods of its existence, may be greater than at later periods,—a given power of elastic vapours and gases having less resistance to overcome after a free vent is first formed, than when such vent is clogged up by a column of lava, cinders, and the like, supported by a large conical heap of cinders and ashes bound together by hard radiating lines of accumulated lava-currents. Consequently, all other things being equal, we should expect more subordinate lateral cones, and fewer eruptions from the central cone, in a volcanic vent which had been long in activity, than from the same vent at earlier periods of its existence. It will be evident, that the observer cannot well infer the relative antiquity of two volcanos, such as Etna and Vesuvius, because the one is larger than the other, and lateral cones exist on the one and not on the other, unless he could show that the

volcanic forces of the one are always equal to the forces of the other, and accumulate equal quantities of matter, producing equal antagonist action, in equal times.

e. Observations on the chemical composition of the various vapours and gases ejected during a volcanic eruption, as well as of those thrown out from crevices and fissures in the crater and sides of the same volcano in a state of minor activity, or of repose, as it is frequently termed, are highly important, because they lead us to a knowledge of the cause of volcanic action itself. It is at present a somewhat prevalent theory, that volcanic action is caused by the percolation of sea, or of other water containing the same salts in solution as those found in the sea, to certain metallic bases of the earths and alkalies. To try the value of this, or of any other theory founded on the percolation of water to volcanic foci, it will be evident that examinations of the vapours and gases evolved from volcanos at various distances from the sea, or other large bodies of superficial water, are important. The observer, if a chemist, will readily proceed to the examination in a manner to ensure success. If he be not a chemist, he may still collect the vapours and gases for examination, by attending to the following instructions :—

He should select glass-bottles to which stoppers have been accurately fitted by grinding ; and he may himself grind stoppers into the bottles, or improve their fit by means of fine emery moistened with water. The bottles should then be filled with spring-water (or distilled water if at hand), be emptied as close as possible to the spot whence the gaseous matter is issuing, and then closed before removal from the spot. The stopper

should be first smeared with a thin layer of spermaceti ointment or candle-grease, and its line of junction with the neck of the bottle be covered with cement made of wax melted with half its weight of resin. The stopper should then be tied down tightly with twine. Bottles capable of holding two, three, or four ounces of water suffice for most purposes; but larger ones, if at hand, should be preferred. If bottles with glass-stoppers are not to be had, common wine-bottles and corks may be substituted. The cork should be first softened by percussion between two flat pieces of stone or wood; and when tightly introduced, any portion of the cork projecting above the mouth of the bottle should be cut off, and its surface covered with wax-cement or sealing-wax melted upon it.

f. If there be not too much danger attending the approach to the craters of volcanos at periods of active eruptions, the gases and vapours should be collected at different times during such eruptions, in order to ascertain if any change take place in their character or relative proportions at such times. It is generally considered that carbonic acid gas, when evolved, is thrown out towards the close of some considerable eruption.

g. When practicable, the various sublimations observed in fissures and other situations in volcanic craters should be obtained with care; those liable to deliquesce, or suffer change by the action of the atmosphere upon them, being preserved in bottles with ground glass stoppers and well sealed, so that when subsequently examined they may be as nearly as possible in the state in which they were obtained at the volcano. A comparison of such products obtained from various volcanos

differently situated would assist in advancing our knowledge towards a true theory of volcanic action.

h. With regard to the liquid melted rock, or lava, ejected from a volcano, its chemical and mineralogical composition will necessarily depend upon a variety of circumstances which an observer can have little opportunity of knowing. Its principal character will be that of the mass whence the body of lava is derived, whether such mass be composed of the oxides of certain earths and alkalies then first formed by the percolation of water to their metallic bases, or of liquid heated matter produced by other causes. The depths whence lava is generally derived is probably far beneath the surface of rock exposed to our examinations in the localities where it is ejected. An observer may, however, endeavour to see if there may be any connexion between the chemical composition of the lavas thrown out of any given volcano, and that of the rocks forming the district generally. Portions of rock that are evidently parts of those found in the surrounding districts are ejected from some volcanos. Thus pieces of limestone have been ejected from Vesuvius of the same kind as those forming the surrounding calcareous mountains, so that the volcanic vent probably traverses a subterranean continuation of the rocks composing these mountains, and portions of them are occasionally there broken off. If these had not been suddenly thrown out, they would probably have been melted in the common mass of lava, the carbonic acid being driven off, and the lime combined with silica, rendering the whole mass more fusible from the presence of a larger proportion of silicate of lime. Many argillaceous slates, and rocks of the mine-

ralogical character of those termed grauwacke, may
readily be converted into pumice by a little manage-
ment in our furnaces ; so that we can conceive the pu-
mice of the ancient volcanic district of the Rhine to
have been portions of the grauwacke of the neighbour-
ing country converted by heat into that substance. It
must not, however, be supposed that all pumice is thus
derived.

i. It would be desirable for an observer to detach
specimens of a fair general character from lava-currents
of different ages ejected from the same volcano, in order
to see if there be any marked chemical difference in
their respective compositions, such as might lead to the
opinion that the conditions under which the lava has
been produced have varied during the time which has
elapsed since the volcano first ejected liquid melted
rock.

k. It would also be desirable to observe, among the
more ancient volcanic conglomerates, if any such be
exposed around a volcano whence portions of non-
volcanic rocks are ejected, whether similar portions of
rocks be more numerous in them than would probably
be the case in the conglomerates now produced around
the same volcano ; because, if found to be so, there has
been a change of conditions under which such fragments
of non-volcanic rocks have been thrown out. We can
readily conceive, that when volcanic substances are first
discharged through a vent situated among non-volcanic
rocks, there would be a greater tendency to drive off
and eject portions of the latter than when the passage
had in some measure been cleared of points of resist-
ance. If the converse be observed,—that is, if portions

of non-volcanic rocks be not discovered in the older con-
glomerates of a volcano, while such fragments be now
ejected from its crater,—some change of conditions must
still have been effected, though produced by other
causes than that noticed above as probable.

l. The extent to which fragments of rock, portions
of liquid lava, cinders, and ashes may be scattered
around a volcano in a state of violent eruption, should
be noted, in order that we may duly appreciate the cha-
racter of the resulting deposit, whether it be effected on
dry land, or beneath fresh-water lakes or the sea.   The
distance to which the lighter ashes may be carried by
atmospheric currents is well known to be considerable.
It would be desirable to ascertain the chemical compo-
sition of such finely comminuted volcanic matter, in
order to appreciate any change that may be subse-
quently produced in or by it, whether it fall upon land
or water.

m. The vapours and gases evolved from Solfataras,
as they are termed from the Solfatara near Naples,
should be examined with care ; and the chemical pro-
ducts resulting from their action upon the lavas, cin-
ders, and ashes they may encounter, should be noted.
Solfataras may to a certain extent be considered as vol-
canos in a semi-active state ; the relatively small amount
of vapours and gases produced readily finding vent, as it
were, through a safety-valve, no explosions of highly
compressed elastic matter take place, and consequently
no piles of solid substances, driven upwards by such ex-
plosions, are accumulated at the mouth of the vent in
the form of a cone with a funnel-shaped cavity at its
apex and down its axis.

n. If the observer study the internal portions of vol-
canic cones, exposed by various causes to examination,
he will frequently find lines of solid rock cutting beds
composed of cinders, ashes, and the like, as in the
annexed sketch (Fig. 61), in which *a b* represents a

Fig. 61.
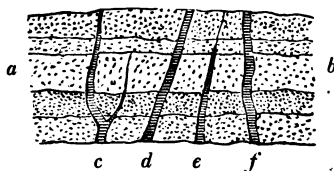
horizontal section of conical or other coatings of cinders
and the like, traversed by the lines of solid rock, *c d e f.*
These lines of solid rock are termed volcanic dykes, and
are the result of fissures in the beds *a b*, (caused by the
heaves and throws of the volcano during times of acti-
vity,) filled by liquid lava, which has either risen or been
ejected into them. An observer should examine the
mineralogical composition of these lava-dykes, noting
how far the same elementary substances may have com-
bined, or been arranged, differently in the matter of the
dykes and in that of the common lava-currents of the
volcano, in consequence of the different conditions to
which they have been respectively subjected. He should
also note to what extent, if any, the particles of the ash
or cinder beds near the dykes may have been compelled
to arrange themselves, when exposed to the heat of the
lava filling the fissures, differently from the relative
positions they previously occupied, and which relative
positions similar particles still occupy in other and con-

tinuous portions of the same beds. The alterations, as they are termed, thus caused, are sometimes highly deserving of attention.

XI. *Earthquakes.*—The geological importance of earthquakes consists in the elevation and depression of land that may be produced by them, particularly when such elevations and depressions take place on the shores of lakes or seas, or across the lines of river-drainage on land, and there is a consequent alteration in the physical features of districts. They also produce cracks and dislocations in the solid surface of the earth.

a. The magnitude of the area agitated by any given earthquake is an object of considerable importance, inasmuch as it is one of the chief elements to be taken into consideration when we search into the cause of earthquakes. It will be obvious that no single person can, from his own observations, estimate the area agitated by an earthquake, though much may be accomplished by the combined observations of many. It is therefore important that a similar series of notes should be taken by various observers, whenever earthquakes occur under circumstances which may enable them to do so.

b. Earthquakes are generally stated to be felt in lines, sometimes in one direction, sometimes in another. It is consequently desirable to learn whether such lines form portions of great curves, and may therefore appear straight for comparatively short distances, or are really straight, as regards any given direction on the earth's surface, for long distances. This knowledge also can only be obtained by the combined observations of several persons. Mr. Babbage has suggested a simple, and,

as it appears to us, certain means, of registering the direction taken by an earthquake. It consists in partly filling some convenient glass-vessel with treacle or other viscous fluid, which, when lateral motion is communicated to it from the earth, is marked in two opposite directions by the wave produced in the treacle or other viscous fluid. A line drawn across the two highest and opposite points marked by this wave would give the direction of the shock by which it was produced.* If instruments founded on this principle were constructed alike in every respect, we might not only obtain the

Fig. 62.
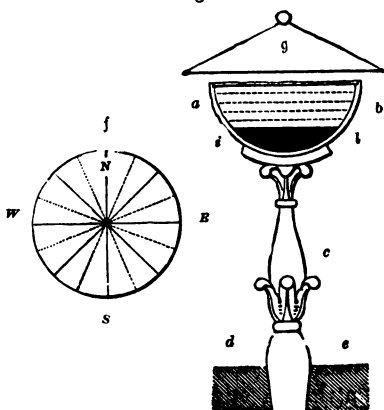
direction of earthquakes, but some information respecting their intensity at different places. Let *a b* in the annexed sketch (Fig. 62) be a hemispherical basin of a

* " Economy of Manufacturers," 2nd edit. p. 58.

given size, formed of glazed earthenware or glass, as
may be considered most convenient, filled up to the
height *i l* with treacle or any other substance consi-
dered most likely to attain the end desired.   Let equi-
distant horizontal lines be marked in the interior of the
basin from the treacle to the rim ; and let the basin be
tightly fixed upon a perpendicular pedestal, *c,* driven
firmly into the ground, *d e,* in some sheltered court or
garden, away from any vibrations produced by accidental
causes in a dwelling-house, and from the fall of any build-
ing upon it during an earthquake.   To keep the inte-
rior of the basin clean and free from insects, a circular
glass disc should cover its rim exactly ; and in order to
render this disc still further useful, the various points,
North, South, &c., should be correctly marked in lines,
as at *f,* upon it, so that the lines of the disc being ar-
ranged to correspond with the *true,* not the compass,
North and South, the direction of the wave produced
by the shock of an earthquake may be at once seen,
without first disturbing the basin.   In situations where
sufficient protection from the weather is not afforded to
the instrument, a conical covering, *g,* should be sup-
plied.   Such instruments would essentially cost but
little, and might be extensively employed in countries
agitated by earthquakes.   By their means we should
not only obtain the direction of shocks, but some infor-
mation as to their intensity, as far at least as a greater
or less waving motion of the earth was produced, by
the relative height to which the treacle or other viscous
fluid might rise in the basin.

   c. Supposing the above or any other convenient in-
struments constructed for similar purposes were exten-

sively distributed, we might eventually learn whether, as in the annexed sketch (Fig. 63), supposed to represent some given portion of country, there was a point,

Fig. 63.
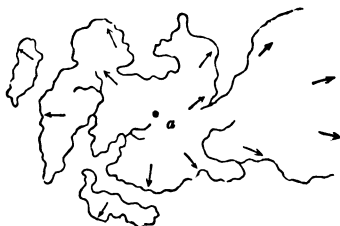
a, from which the various shocks seemed to radiate, decreasing in intensity as they receded from *a* as a centre ; or whether, as in Fig. 64, they followed a long marked

Fig. 64.

line of direction, *a b*. In the first case, we should have a centre of disturbance, and consequently the cause of the earthquake produced vibrations around it. In the second, we do not know that any portion of the superficies of the globe has been so acted on as to produce vibrations from a central point of some part of such superficies outwards. The vibration may merely have run along a line of some great previous fracture of the earth's crust, upon which a force acting upwards, from a

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situation deeply seated beneath the surface, would more
readily produce vibrations, from the comparatively less
resistance of parts in that or similar lines, than in por-
tions of the earth's surface not so fractured.   As it is
no part of our object to press particular theories upon
the attention of the observer, we must refer to geologi-
cal works for those which account for earthquakes, leav-
ing him to adopt such as may appear the most probable.
He will perhaps come to the conclusion, that the vibra-
tions of the earth's surface, commonly termed earth-
quakes, may be due to more than one cause.   If so, he
will expect a difference in the effects produced, and con-
sequently look to detailed observations, made with the
best means in our power, for those facts which, being
subsequently classified and duly weighed, may ulti-
mately lead to the knowledge required.

   d. Let earthquakes be caused by what they may, the
vibrations produced by them will be modified and dis-
turbed by the nature of the substances through which
they pass.   An observer, therefore, should direct his
attention to the compactness or other characters of
rocks in districts agitated by earthquakes.   A force act-
ing with a given intensity may produce very different
vibrations in rocks of different structures, and the force
may in some cases be just sufficient to cause vibrations
in one rock and not in another, so that an earthquake
may be felt in the line of one rock and not in another.
As, however, the effects resulting from this cause would
greatly depend upon the relative position of the rocks,
due care should be paid by the observer to this circum-
stance. · Rocks also piled horizontally upon each other
might transmit vibrations through them more readily in

that position, from the action of a given force, than when the same rocks were in a perpendicular position and acted on by the same force; because, in the latter case, the resistance would probably be greater than in the former. Let a, b, c, d (Fig. 65) be four rocks lying

Fig. 65.   Fig. 66.
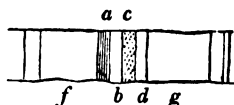
horizontally upon each other, and acted on laterally by a force at e, then there would be less resistance to vibrations than when the same rocks were placed vertically and bound in by other masses of rock, f, g (Fig. 66), and the same force acted laterally upon them in the direction of the eye of the reader.

An observer should endeavour to trace whether there be any coincidence between the general direction of mountain ranges and that of earthquakes, as also whether there may be any such coincidence between prevalent shocks and the direction of strata generally in a district, such strata not having been forced up into mountain chains. He should, however, recollect that the general direction of a mass of rocks, composing a portion of the earth's surface, may be masked by more modern accumulations, and therefore he should endeavour to ascertain if there be any probability of such older rocks running in lines beneath the more modern deposits. For if lines of direction, in stratified rocks, could influence the line of shocks in an earthquake, and the cause of the earthquake act from beneath, such influence

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would be first exercised by the direction of the lowest
rocks, and tend to modify the vibrations produced in
those above them.   Let *a b* (Fig. 67) be a stratified

Fig. 67.

rock, such as grauwacke for instance, and let it have
an east and west direction, and contain in a trough-
shaped cavity other rocks, *c i, d h, e g*, and *f*, in such
a manner that a vertical section would show them to
occur as represented in Fig. 68, where the same letters

Fig. 68.

mark the same rocks as in the horizontal plan, Fig. 67.
And further, let the outcrop, or rising of strata to the
surface, be such, that the lines of the outcrop and direc-
tions of the beds of the rocks *c i, d h, e g*, and *f*, be
N.N.E. and S.S.W. nearly.   Then if shocks of an
earthquake be found to take an east and west direc-
tion, at any situation upon the rocks *c i, d h, e g*, and
f, it should not be too hastily concluded that they are
not influenced by the direction of strata beneath, be-
cause the superficial rocks have a direction N.N.E. and
S.S.W. ; since, in this case, the shocks in question, if
influenced by the direction of the lower rocks, would

coincide with the direction of the strata of the rocks *a b,* because they would be first acted upon.

e. If after earthquakes there be reason to consider that land has either been raised or depressed by the shock or shocks, great care should be taken to ascertain correctly the amount of such rise or depression. For the most part, the general sea-level is that which is not only the most convenient, but most certain, for purposes of comparison. To produce any great change in it by any cause which can alter its level, there must be such an amount of solid matter moved up or down beneath the ocean, that the term earthquake, as usually employed, could not apply to such an exercise of subterranean force, be the cause of the force what it may.

An observer should most carefully measure any rise or depression of a coast, produced by an earthquake, with the mean surface-level of the sea before and after the event ; the exact difference between the two being the true measure of the rise or depression, as the case may be. It is probable that by a due attention to exactitude in this respect, proper allowances being made for the variable height of tides where such occur, and for the influence of winds in locally raising or depressing the sea-level at a time of observation, the rise or depression of land from earthquakes would sometimes be found greater and sometimes less than the measures often given.

It is necessarily a difficult process to trace any such rise or depression inland, unless the country be one in which the height of a variety of points, above the sealevel, has been ascertained with exactitude, when any change in their relative heights would afford that of the

rise or depression caused by an earthquake. There is scarcely a country the heights of which are measured with such precision as to afford exact data for this purpose; though there are, no doubt, some countries of which certain points seem to have been most accurately ascertained. If, however, the general drainage of a country rise inland, as is commonly the case, observations on the velocity of rivers would be found valuable, when their previous velocities are known, as sometimes happens, to a certain extent, where mill-dams or other obstructions cross a river, and, consequently, where any change producing a greater or less slope in the river-bed is soon detected. It is extremely desirable to obtain precise information upon this subject; for, hitherto, calculations intended to give an idea of the cubic contents of masses of land, either raised or depressed by any given earthquake, have not rested on such data as could be desired. They may readily have been either greater or less than those calculated.

f. Although it would generally be exceedingly difficult to estimate the depth to which any given line of coast may have been depressed beneath the sea-level by a succession of earthquakes, unless sufficient historical documents exist to do so, the height to which it may have been elevated by such means may be inferred, if an observer discover a series of beaches elevated above each other on a coast known to have been raised by any earthquake, the last beach having been clearly elevated by such means. Due care must, however, be taken to estimate the value of other causes which may have produced the effects observed.

g. In cases where the bottom of the sea is considered to have been raised by an earthquake, and a neighbouring volcano has been in a state of activity at the time, an observer should endeavour to ascertain if any considerable amount of ashes and cinders has fallen into the sea in the situation where the bottom has been supposed to have been thus elevated. He should also direct his attention to the sea-level on the adjoining coast. If there be no relative change as regards the level of the sea-line on the coast, and there has been a considerable fall of cinders and ashes in the locality considered to have been raised, the supposed rise caused by an earthquake is probably deceptive. Even on coasts where there has been no fall of volcanic substances, proper allowance should be made for the addition to beaches in favourable situations, produced by the great breakers generally discharged with great fury on coasts during earthquakes. These accumulate a great body of detritus in such situations, upon the same principle that the breakers, during a heavy gale on shore, accumulate greater beaches in front of low land than in more moderate weather. Proper attention should also be paid to the probable accumulation of live molluscs, corals, &c., by such breakers, the result of waves which tear up the sands and mud, and break off portions of corals, sea-weeds, &c., and discharge them on shore, on the same principle that minor breakers and waves near coasts do so during gales of wind. We are desirous to place an observer on his guard where circumstances may be equivocal, and that, under such circumstances, the mere addition of height to a given beach, or a long line

of accumulated live molluscs, &c., may not be consider-
ed good evidence, in the absence of better, of a rise of
land from an earthquake in that particular situation.

  h. It can scarcely be expected that during those
earthquakes where rents and fissures are produced in
the ground, an observer can calmly direct his attention,
amid the danger which surrounds him, to the gases or
vapours which may escape from such rents and fissures.
He may, however, be conscious of any particular odours
that may escape from the fissures, as also of any appear-
ance of flame.   The latter is sometimes stated to have
been witnessed ; and if the appearance has not been
deceptive, it is desirable to possess such data respecting
it as may lead towards a knowledge of its cause.   The
exact amount of dislocation of rocks caused by an earth-
quake should be carefully noted ; and the number of
feet which one side of a fissure may rise or fall above
or beneath that of the other should be ascertained, ob-
serving whether such relative change in the level of the
rocks on either side be produced by a rise or fall gene-
rally of the land around.   It is exceedingly desirable
that all such changes be measured, and the exact mea-
sures recorded ; and that they be not merely described
as ' enormous !' ' stupendous !' and the like, when, per-
haps, a change of level produced in the two sides of a
fissure, and thus characterised, may not be more than
from four to ten feet.   When noticing such terms, we
cannot but express a hope that they may be omitted in
geological descriptions, since they convey no definite
ideas of height, depth, or distance, and lead only to
vague, and, for the most part, exaggerated, notions of
things which can readily be measured.   We once mea-

sured, and reached the bottom of, a ' fathomless abyss,'
with a line of about ninety feet ! and have seen ' enor-
mous dislocations,' so trifling that they were difficult to
discover.

   i. The direction of any fissures or ridges of raised
ground, caused by earthquakes, should be carefully ob-
served, and their length and breadth as accurately noted
as possible. Whether they run in lines parallel to each
other, or radiate from some central point, should also be
ascertained ; and whether, if parallel, the dislocations
have been effected in the manner represented in the
annexed imaginary cross section (Fig. 69), where the

Fig. 69.
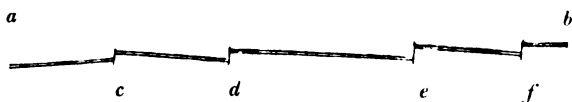
surface of a nearly level tract of land, *a*, *b*, has been so
dislocated in parallel lines, *c*, *d*, *e*, *f*, that three ridges
and depressions have been produced. All changes and
their probable consequences in the physical features of
a country, either ridged, furrowed, or otherwise altered
by the effects of earthquakes, should be noted ; and
when numbers can be used to convey definite ideas of
such changes, they should be employed. Thus, instead
of informing us that the course of a river has been
arrested by an earthquake, that a lake has been the con-
sequence, and that this lake, when it ' bursts,' would
excavate valleys, &c. we should be informed whether a
river had been stopped by the fall of loose rocks and

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other substances in a ravine or other situation where such an effect could be produced, or whether a ridge caused by an earthquake had dammed back the waters of a river; in either case, giving us the height, breadth, and composition of the dam.   When accumulations of water are produced in consequence of rivers arrested in their progress, we should have some definite description of their length, breadth, and depth, and consequently of the body of water they may contain ; so that, when it is inferred that valleys may be excavated by the ' bursting,' as it is termed, of such lakes, we may be enabled to judge of the manner in which the waters may obtain a passage through the dams, and of the probable effects which may be thus produced.

XII. *Gradual rise or depression of large tracts of land, unaccompanied by shocks of earthquakes or other sudden movements of the earth's surface.* — For more than a century it has been observed that a change was slowly taking place as regards the relative position of sea and land in parts of the shores of Sweden bathed by the Baltic ; and Von Buch long since asserted that the surface of Sweden was gradually rising from Frederickshall to Abo, and that such rise probably extended into Russia.   Of late this important circumstance has received that further attention that it deserved, and it has been asserted that the rise of land was unequal, taking place more on the north than on the south ; so that the rise is at the rate of four feet in a century in the northern part of the Gulf of Bothnia, and not observable in the islands of Œland and Gottland.

a. When such an elevation of land is suspected, ob-

servations to ascertain the fact should be conducted with great care, and with due regard to those local circumstances which may affect them. It is evident that, in the first place, proper marks should be made on cliffs or other sufficiently stationary objects, showing the height of the sea-level as regards the coast at some given time. To fix upon such level is no inconsiderable difficulty, in tidal seas especially. Even considering that tides, taken by themselves, so occur that a mean might be obtained of their height at any given place, it scarcely happens that they are not modified in their exact height by the pressure of the atmosphere at the time, and by the state of the winds generally in a considerable area around the given locality. After the prevalence of a strong wind on shore for some time, it frequently happens that high water is kept up beyond the proper time in harbours, and the level of the tide is forced up, even to as much as two or three feet, beyond what it would have been if there had been no strong prevailing wind on shore. When a strong off-shore wind continues for some time, the reverse happens; and what is thus true of high water is also true of low water. These effects are again modified by the state of the tides at the time; much depending upon their being springs or neaps, as they are technically termed.

b. In tideless seas, such as the Baltic and Mediterranean are commonly termed, though they cannot obviously be strictly so, similar precautions as regards the pressure of the atmosphere and the state of the winds during an observation are necessary, otherwise very serious errors may be committed. It is well known that the Baltic is kept up at least two feet by a strong and con-

tinued north-west wind; the Caspian sea is higher by several feet at either end according to the prevalence of a strong north or south wind; and it is equally well known that the height of the sea in the ports of the Mediterranean is greatly influenced by the state of the winds for the time.

c. In noticing the foregoing sources of error, we by no means intend to throw doubt on the probable slow rise and depression of land now taking place in various parts of the earth's surface : on the contrary, we believe that they do occur more generally than has been hitherto supposed, and we have repeatedly stated our opinion that such gradual rises and depressions of the solid part of the earth's surface are necessary to explain many geological phenomena observable in the fossiliferous rocks, as well ancient as modern.*   We merely desire to call attention to certain necessary precautions, when a given locality or line of coast is under examination, so that, in the first place, there may be a certainty of the locality or of the coast rising or sinking, as the case may be ; and in the second, that, if the one or the other be matter of fact, there may be no error in the *amount* of elevation or depression stated to take or to have taken place in a given time.

XIII. *Temperature of the Earth.*—We include under this head observations on the temperature of rocks, &c. in mines, and on the temperature of seas, lakes, Artesian wells, and springs.   We shall abstain from pressing particular theories upon the attention of the observer, leaving him to adopt such as may

* See " Geological Manual," and " Researches in Theoretical Geology."

appear to accord best with the phenomena he may
notice.

a. In observations of this kind it is essential that the
thermometers employed should be of the best possible
construction,—not graduated in the common way by
merely noting the freezing and boiling points of water
at a given height of the barometer, and then marking a
certain number of equal parts between these points,
according to the scale adopted ; but by carefully verify-
ing the graduation at numerous points with standard
thermometers, constructed with every requisite care.
In delicate observations of this kind regard should be
paid to the age of the thermometer itself, since it has
been found that in mercurial thermometers the freezing
point slowly rises after graduation ; and as the princi-
pal effect is produced soon after the tube is sealed, it
has been recommended that some months should elapse
between the sealing and graduation of a thermometer.

b. The numerous sources of error which may influence
observations on the temperature of the air or water in
mines or collieries, though they may be conducted by
very skilful and experienced persons in such a manner
as to ensure success, when the sources of error are duly
considered, are such that more direct observations should
be preferred whenever practicable.   Great care should
obviously be taken to avoid any source of error either in
the instruments or other means employed.   The follow-
ing was the process adopted by M. Cordier, who has
given great attention to this subject, when he obtained
the temperature of the rock itself in some coal-mines of
France :—The thermometer was loosely rolled in seven
turns of silk paper, closed at bottom, and tied by a string

a little beneath the other extremity of the instrument, so that so much of the tube might be withdrawn as might be necessary for an observation of the scale, without fearing the contact of the air ; the whole contained in a tin case. This was introduced into a hole from twenty-four to twenty-six inches in depth, and one inch and a half in diameter, inclined at an angle of 10° or 15° ; so that the air once entered into the holes could not be renewed, because it became cooler and consequently heavier than that of the galleries. The thermometer was kept as nearly as possible at the temperature of the rock, by plunging it among pieces of rock or coal freshly broken off, and by holding it a few instants at the mouth of the hole, into which it was afterwards shut, a strong stopper of paper closing the aperture. The thermometer generally remained in this hole about an hour.*

Observations have also been made by drilling a hole, a yard or other convenient measure in depth, in the rock of a mine, and observing the temperature during any given period, such as a year or more. It may be stated, that from the observations hitherto made on the temperature of the rocks in mines, and, even with every allowance for error, on that of the air or water of such situations, there is an increase of temperature downwards from that depth where changes of temperature are not produced by the climate to which the actual surface is exposed. It is scarcely necessary to state, that observations should be made on rocks at various depths, and in situations as little as possible under the

* Essai sur la Température de la Terre: Mém. de l'Acad. tom. vii.

influence of heat occasioned by the presence of miners with their lamps or candles, by the blasting of gunpowder, or by a mixture of iron pyrites, water, and shale, where such occur.

c. Observations on the temperature of the sea at different depths may for the most part be made with those thermometers commonly termed register, in which the graduated tubes are placed horizontally, a mercurial thermometer pushing forward an index to the greatest heat to which the instrument has been exposed in the sea, while an alcohol thermometer draws back on another index to the greatest degree of cold to which it has been subjected ; so that the observer learns the extremes of temperature to which the whole instrument has been exposed after it quits the surface. Observations, therefore, at considerable depths might be considered uncertain with such an instrument, if care be not taken to obtain the temperatures of the sea at various intermediate depths, since changes might have happened at such various depths, and the register thermometer merely marks the extremes of temperature to which it has been subjected. There are various other instruments, a knowledge of which an observer may readily obtain at the best philosophical instrument makers, contrived for the purpose not only of taking the temperature of the sea at various depths, but also of obtaining water at the same depths.

Of whatever kind the instrument employed may be, in all those in which the temperature of the water is not taken after a portion of the latter has been withdrawn from any given depth, but in which a thermometer is made to descend in the sea, it is necessary that the

materials of the instrument employed, viewed as a whole, should be such as readily to take the temperature of the depth to which it may be plunged, and that the thermometer should have some contrivance for registering the temperature ; since the same materials which speedily take the temperature at various depths, as readily permit the thermometer to be affected by changes in the temperature of the water when drawn upwards to the surface.

In cases where an observation may be rendered uncertain by a shock of the instrument employed upon the bottom of the sea, when such bottom may be touched by the length of line to be run out, it is desirable to have the sounding lead so arranged, with respect to the instrument for obtaining the temperature, that when the former touches the ground, the line may be held firm and the lead raised above the bottom, so that the jerks, which might be caused by the pitching or rolling of the ship or boat above, and derange any index for registering temperatures, may be as much as possible avoided. We have often arranged the line, instrument, and sounding lead upon the principle repre-

Fig. 70.

sented in the annexed woodcut (Fig. 70), and have found it answer the purpose intended:—*a* is a line leading up to the boat or ship; *b*, a point where another line, *e*, supporting the instrument for ascertaining temperatures, *c*, is attached to it; the main line, *a*, being continued down to the sounding lead, *d*. The line *e* supporting the instrument may be of any convenient length, and that of the main line, from the point *b* to the sounding lead *d*, either ten, one hundred, or any other number of feet, as an observer may think proper.
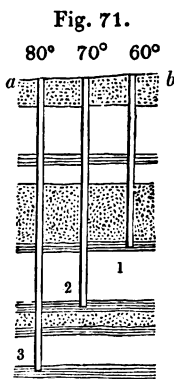
It will be obvious, that when the lead *d* touches the bottom, and is felt by the person sounding, the line should be held firm, so that the instrument does not strike against the ground.   If the bottom of the lead *d* be armed, as it is termed, in the usual manner, the temperature of a given depth, the actual depth of the sea at a given place, and the kind of bottom, are all ascertained at the same time.

d. Observations on the temperature of the sea are to a great extent simplified by the fact, that sea-water attains its greatest density at about the temperature that it becomes ice; so that in situations such as the tropics, where the surface temperature never approaches that of the freezing point of water, there would be a constant decrease of temperature downwards, and the lowest temperature would not be so low as the freezing point of sea-water.   In the colder regions of the globe, where the surface-water is so exposed to temperatures producing densities which may either cause it to keep its place, or descend within a small range of the thermometer, variations of temperature will occur which it will require very great care on the part of the observer to ascertain.

e. The temperature of lakes of fresh water may be obtained with the same instruments and in the same manner as that of the sea.   Such observations are, however, rendered still more simple by the knowledge of the fact, that fresh water attains its greatest density at a temperature of between 39° and 40° of Fahrenheit's scale, and consequently that all fresh water of a greater or less temperature will float above water of that temperature.   The observer should direct his attention to

the depths to which the variations in the heat of cli-
mates extend in deep lakes, endeavouring to ascertain
those beneath which the temperature remains nearly the
same throughout the year, under ordinary circumstances.

f. It has been found that, viewed generally, the tem-
perature of the waters rising to the surface in those per-
pendicular perforations into the earth, named Artesian
wells, increases with the depth whence the water has
been derived. If allowed to remain at rest, the waters
in such perforations would endeavour to arrange them-
selves according to their relative specific gravities, and
therefore according to their densities, the warmest water
being uppermost, considering the whole column of
water to be above 40° Fahrenheit. Consequently, ac-
cording to the original temperature of the water beneath
would be the observed temperature above, and therefore
if comparatively warm waters were found at the top of the
deepest perforation, even when the waters did not flow over
the surface, the original temperature of

such waters would increase according
to the depth of the Artesian well.
Let 1, 2, 3, (Fig. 71), be three Arte-
sian wells of different depths, perforat-
ed perpendicularly downwards from
the surface, *a b :* if an observer now
find the respective temperatures of the
surface-waters of these wells, even
when they do not flow over the surface
a b, to be, for the sake of illustration,
equal to 60°, 70°, and 80°, he would
have evidence that the temperatures

Fig. 71.

depended upon the depths, all other circumstances be-

ing equal, notwithstanding he might procure more equal temperatures by sinking towards the bottom of each well.

Artesian wells, however, generally flow over the surface from which they are perforated ; indeed their economical value depends upon this circumstance. The force with which they rise is commonly such, that the water cannot arrange itself in the perforation or pipe according to relative specific gravities ; so that, when it reaches the surface, particularly after the flow has continued some time and the sides of the Artesian well have acquired their proper temperature, the water will be nearly of the temperature of the deep-seated source whence it is derived. An idea of the force with which the water rushes to the surface in some Artesian wells may be formed, when it is stated, that in one formed at Tours, and perforated to the depth of eighty-eight feet beneath the level of the Loire, the water rises to from thirteen to sixteen feet above the surface of the land, with such force that a tin cylinder containing twenty-two eight-pound balls was thrown out when introduced into the perforation. In such a case there would be little chance of error by considering the temperature of the water, when it comes to the surface, to be that of the same water at the depth of eighty-eight feet.

An observer should be on his guard against the possibility of some of these waters being thermal, and that they may have been prevented from rising in the usual way to the surface by the gradual accumulation of beds of rock, which, having been artificially pierced, permit a portion of the waters to escape. We notice this, in case it should ever be observed that the temperature

of Artesian wells, which discharge a large volume of water in a given time, should be found to rise slightly, which we might expect if thermal waters gradually acquired a more free passage to the surface than they at first possessed. If thermal waters rose to a surface considerably beneath that of the soil in any given district, and there spread out in tabular sheets between strata, it will be evident that they would eventually take the temperature of the strata between which they occur; and, therefore, if they are subsequently and suddenly conveyed to the surface by artificial means, they will afford the temperature of rocks at known depths.

g. It having been considered that common springs in the tropics possess temperatures lower than those of the climates in the same localities, and that those of the cold regions of the globe are, on the contrary, higher than the mean of the climates in such situations, it becomes important to ascertain the temperature of common springs with precision, in order to see how far the facts may be general. If they be general, there will be some modifying influence distributing a more uniform heat over a certain depth beneath the earth's surface, than would appear probable from the mere effect of solar influence. As very great exactitude is necessary in observations of this kind, every care should be taken duly to estimate any causes of error which may present themselves.

In the first place, the observer should, if possible, ascertain the condition under which the springs exist. Some modification of the conditions represented in the annexed vertical section (Fig. 72) is not uncommon. Let *a* be a porous rock—a slightly aggregated sandstone,
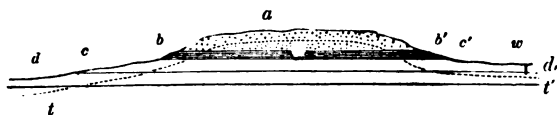
for instance—resting on a bed, *b b'*, nearly impervious to water, such as clay ; then rain-water falling upon the top of the hill is in a great measure absorbed by the porous rock *a*, but its progress downwards being check- ed by the clay, or other nearly impervious bed, *b b'*, it comes filtering out in the shape of springs on the side of the hill at the level *b b'*.   Let us, for further illus- tration, suppose another porous rock, *c c'*, to occur be- neath *b b'*, and that in its turn it is supported by a bed of rock nearly impervious to water, *d d'*; then the rain falling upon the rock *c c'*, will be first absorbed and afterwards filter out in springs on the side of the hill at *c*, but not at *c'*, because the nearly impervious bed *d d'* is not exposed on the surface in that direction.   But if a well, *w*, be sunk on that side of the hill, the same water will evidently be obtained as at the junction of the beds *c* and *d* on the other side of the hill.   The water in these cases is first at the temperature that it takes in the atmosphere; but percolating through the rocks which absorb it, it becomes of their temperature. Now, if these rocks vary in temperature according to their depth beneath the surface of land, there would be a line of uniform temperature, represented by the dotted line *t t'*, parallel to, and beneath, the actual surface, *d c b a b' c' w* ; and consequently, if water percolates slowly to the surface in the shape of springs, it would probably take the temperature of the rocks, all other things being equal, between the line *t t'* and such surface ; whereas, if

it rose more rapidly, it might carry with it the tempera-
ture of lower depths, in proportion to the volume of
water discharged and the velocity with which it was so
discharged.   Hence the quantity of water delivered by
a spring in a given time, and the rapidity with which it
rises, require to be duly estimated.

Other springs again are evidently not modifications
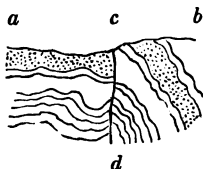of the above conditions. They sometimes rise from dis-

Fig. 73.

Fig. 74.
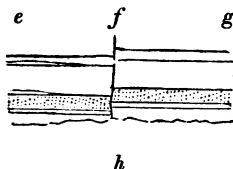
locations of rocks, commonly termed *faults ;* such are
represented in the sections above (Figs. 73, 74), where
f h represents a dislocation of nearly horizontal rocks ;
c d, another dislocation of disturbed rocks.   In such
cases we cannot be certain that the waters, rising through
the fissures *c d* and *f h*, to the respective surfaces *a b*
and *e g*, may not be derived from great depths, and
bring the temperatures of such depths with them to the
surface, modified by any change they may suffer in ris-
ing upwards, which depends, as we have before seen,
upon the rapidity with which this can be accomplished,
the volume of water being duly considered.   This
caution is the more necessary, since warm or thermal
springs commonly appear to rise through fissures, and
would in such cases necessarily be modified in tem-
perature according to obvious circumstances.

Springs in limestone countries frequently rush out with great force : they may in some instances be termed small rivers. This arises from the cavernous character of such districts, and the generally ready manner in which rains are swallowed up in cavities communicating with the surface ; often also from the highly tilted character of the beds in such districts. In the great tract of country formed of compact white limestone in Jamaica, this fact is remarkably exhibited. Notwithstanding the heavy fall of tropical rains in that district, nearly the whole is immediately swallowed up by innumerable holes and caverns, which join in subterranean passages ; so that a spring, properly so called, can scarcely be seen for considerable distances, while here and there a small river rushes to-day from amid the rocks. To judge of the temperature of the earth, at those relatively small depths where climate ceases to have an influence, by that of such waters, will depend upon the time the latter may have remained beneath among the rocks, so that they should acquire their temperature.

The observer should therefore weigh well the conditions under which the springs he may examine come to the surface, and, when he notes their temperatures, should also note so many of such conditions as he can ascertain. In this manner we should ultimately obtain several series of classified facts, and consequently be not only enabled to judge of the relative value of each series, but also of the whole viewed generally. It is necessary to caution an observer against one circumstance which, from experience, we have found to require much attention. In taking the temperature of a spring, he should

clear away the ground so as to get as near as possible to
the spot where the water actually rises from among the
rocks. Without this precaution, an error of two or
three degrees may readily be committed. In thermal
springs it is especially necessary, particularly when the
volume of water discharged is not considerable. The
thermometer should also be introduced into the aper-
ture whence the spring rises : and if the observer be
accustomed to handle delicate instruments, he will find
one of those thermometers in which the bulb and a por-
tion of tube project beyond the graduated scale most
useful, as well as most likely to afford accuracy.

XIV. *Gaseous Exhalations.* — Gaseous exhalations
are observed in many parts of the world in situations
which cannot be strictly termed volcanic. Indeed, in
some places where such exhalations are observable,
there is no trace of modern, or comparatively modern,
volcanic action within considerable distances. As these
exhalations are evidences of chemical action beneath
the immediate surface of the earth, correct observa-
tions on their nature and the conditions under which
they apparently exist become important.

a. When jets of gas escape through fissures of rocks
into the atmosphere, the observer should carefully col-
lect a portion of such gas in the manner recommended
(p. 136) for the gases and vapours ejected from vol-
canos. He should, if circumstances permit, take a
general view of the structure of the surrounding coun-
try, in order to see how far it may assist in affording
information as to the cause of any gaseous exhalation
under examination. Suppose, for instance, the gaseous
exhalation examined should turn out to be one of car-

buretted hydrogen, and the district in which it occurred was composed of rocks containing beds of coal, there would be no very great chance of error in assuming that the gas was probably evolved from the coal-beds. Again, it having been remarked that inflammable gas often appears in the vicinity of saline springs, the observer should direct his attention to this circumstance. Salses or mud-volcanoes, as they are termed, seem the result of chemical action during which much gaseous matter is evolved. Observations should be directed to the conditions under which they occur, and particular attention should be paid to collecting the gaseous products.

b. Gaseous exhalations often bubble up through water. In this case, an observer should take a bottle (of the kinds previously noticed, p. 136), fill it with water, and then invert it with its mouth under the surface of the water through which the gas bubbles up, so as to receive the latter before it enters the atmosphere. A piece of writing-paper, or a large leaf, may be rolled up into the form of a funnel, and serve to direct the gas into the mouth of the bottle. The bottle should be then stopped or corked, and sealed in the manner previously recommended (p. 137).

c. It may be here remarked, that in collecting mineral or thermal waters, which are frequently accompanied by gas, care should be taken to collect as much of the latter as possible. Instead of bubbling up freely, the gas sometimes escapes almost imperceptibly; in which case, a bottle alone would be of little assistance; therefore a vessel having a large opening beneath should be employed, so as to offer a larger surface to the gas rising

I

upwards.   Such a vessel should be secured and left
with its lower rim beneath the surface of the water, so
that when the water which was contained in it, before it
was inverted, is nearly displaced by the gas, it will
merely require a little dexterity in transferring the gas
into bottles; the larger vessel being held beneath the
water, and the gas permitted to escape from it in bub-
bles into the mouth of a bottle previously filled with
water and inverted.   In this way an observer may ob-
tain fair results even without the aid of an apparatus
especially contrived for the purpose.   It is particularly
important to ascertain if nitrogen be always evolved
from thermal springs.   Even when circumstances will
not permit more than a hasty examination of a thermal
or mineral spring, gas contained in the water may often
be secured, if an observer fill a bottle with the least
possible agitation.   The bottles should be all but filled
with the water, and the cement (previously noticed,
p. 137) applied immediately after the cork or stopper
is inserted.

   XV. *Submarine forests.* — In various parts of the
coasts of Great Britain, Northern France, and Ger-
many, collections of trees of species now existing, various
plants, leaves, nuts, &c. are detected at levels beneath
that of high tides, frequently running out to sea, so as
to be exposed only at low water.   These have received
the name of *Submarine forests.*

   a. As some geologists consider that a change in the
relative level of the land and sea in such situations is
necessary to explain the facts observed, while others
suppose that the trees, &c. may have grown and have

been collected in lower situations than that of high wa-
ter, which was barred out by a line of beach, an ob-
server should be very careful in an examination which
requires so much minute accuracy.

In the first place, he should take levels of the local-
ity, and see what depth, if any, the line of trees, &c.
or of the submarine forest—to comprise the whole in
two words—is beneath that of high or of low water, for
the latter sometimes happens.   He should then endea-
vour to ascertain if there is evidence of any portion of
the submarine forest having grown on the spot where it
occurs.   In some cases this will be difficult; but in
others he will find the roots of trees firmly planted in
the ground, and the whole character of the accumulation
such, that he can have little doubt that the leaves,
branches of trees, &c. have been collected around the
roots.   We here suppose that there can be no doubt
that the plants and trees are such as now exist, even in
the neighbourhood, for the observer must be on his
guard against similar effects which may have been pro-
duced at former geological epochs.

b. He has now to consider the general conditions
of the locality, whether it be in front of a valley, of a
larger tract of flat land, or otherwise.   Let us suppose,
for the sake of illustration, that the annexed diagram
(Fig. 75) represents a longitudinal section of one of
these submarine forests; *a b* being the level of high
water, *c d* that of low tide; *e f*, the line of the subma-
rine forest; *g*, a beach thrown up by the sea; and *h*,
sand, silt, or clay covering up the bed *e f.*   In this
case the forest would alone be exposed on the shore at

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Fig. 75.
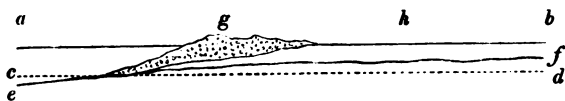
low tide, and an observer would only be aware of its
existence inland by artificial or natural sections which
should cut through *h*.   Now if roots of trees retain the
places in which they grew, not only in the seaward front
of the beach *g*, but also behind it, and the beach itself
be found to rest upon a continuation of the forest, the
beach has evidently been accumulated after the growth
of the forest ; and if any other beach once kept the sea
away from the trees near *e*, such beach has disappeared.
An observer has now to see if the beach *g* rests upon *h* ;
because if it does, then *g* has been accumulated after
the formation of *h*.   He should next endeavour to
ascertain if *h* has been deposited in consequence of
checks offered to the progress of fresh water charged
with detritus seaward, or whether it has been produced
by deposition from detritus mechanically suspended in
sea-water.   This observation is often difficult, except
organic remains be present in *h*, when it can be ascer-
tained whether they are of fresh-water or marine origin.
In the illustration before us—which we have given be-
cause we have found it somewhat common, and not
with the desire of pressing any particular views upon
the reader—the order of events would be : 1. Land so
situated that terrestrial plants, such as oak, yew, fir,
&c. could grow, mixed sometimes with marsh plants ;
2. The growth of the plants and trees, many evidently

to considerable sizes; 3. A relative change of circum-
stances, by which sand, silt, or mud was accumulated in
a bed upon broken stumps of trees, &c.; 4. Another
change of circumstances, by which the sea acted upon
one side of the vegetable accumulation, laying it open
beneath the level of the tides, cutting back its former
covering of mud, silt, or sand, and piling up a beach
which, under ordinary circumstances, bars any further
attack upon that portion of the forest which remains
still covered by its coating of mud, silt, or sand.

c. Correct observations on the substances, such as
gravels, sands, and the like, collected above the inland
portions of submarine forests, are highly valuable. Evi-
dence is sometimes thus afforded of more than one
change of the conditions which have preceded the final
appearance of the submarine forest and associated beds,
under the circumstances which now present themselves.
Sometimes even traces of two accumulations of plants
and trees may be observed, the one separated from the
other by clay, sand, or gravel. An observer should be
careful to notice whether there are traces of such dis-
turbance among the vegetable remains of the forest as
to lead to the supposition that there had been a rush of
water over them, or whether the same remains are so
disposed as to leave little doubt that the causes, what-
ever they have been, which have produced the effects
observed, have acted in a more tranquil manner.

XVI. *Raised beaches.*—We have above noticed
that lines of coast have been raised by earthquakes:
they may be also raised in a slow tranquil manner
by some general and long-continued elevation of land

on the large scale. Lines of beaches are observed on some coasts raised above any waves which could now produce them, and in countries where volcanic action is not apparent.

a. As lines of beach, thus elevated above the present level of the sea, may be of various ages, geologically speaking, though probably none are of any very remote antiquity, when considered in the same manner, it is especially necessary that the observer should carefully search for traces of organic exuviæ among the pebbles or sands of which they are composed. Even fractured shells, when all trace of character is not obliterated, should be preserved. If the beach occur on a coast where the molluscs and other inhabitants of the neighbouring sea be little known, as many of these should be collected as time may allow, for the purpose of comparison with those found in the raised beach. Indeed, the latter is sometimes composed of little else than fractured shells.

b. When an observer discovers a raised beach, he should compare it with that now existing on the coast, in order that he may see how far they resemble or differ from each other. If they resemble each other in the kind of pebbles, sands, contained organic exuviæ, &c., the general conditions of the coast have been the same at the respective periods of the production of both. If they differ, the general conditions have not been the same; and, consequently, according to the amount and kind of difference will be the inferences which may be deduced from the phenomena observed.

XVII. *Erratic blocks and gravel.*—Erratic blocks are large portions of rock which are found at various distances, sometimes considerable, at others small, from the masses of which they evidently once constituted a part. Erratic gravel is formed of smaller portions of rocks also transported to variable distances. For the theoretical conclusions which have been deduced from phenomena of this kind, we must refer the reader to geological treatises ; we merely desire to direct the attention of the observer to a careful examination of any facts, relating to this subject, which he may have an opportunity of examining.

a. As many loose blocks of rock rise above the surface of land, such as pieces of granite, which are merely portions of the rock beneath them that have resisted the effects of decomposition better than it, the observer should be certain that the subjacent rock is different from any block, supposed erratic, which he may have before him. If *a* (Fig. 76) be a block of granite, and

Fig. 76.
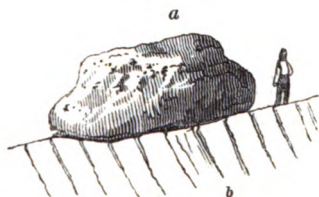
b a series of limestone beds, then he will be certain that *a* forms no part of the subjacent rock *b*, and *may be erratic.* He should next carefully ascertain that the block has not descended by the united effects of decom-
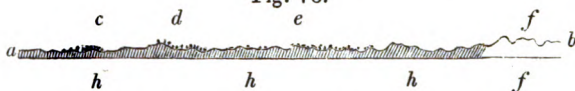
position, gravity and rains, as *a* (Fig. 77) has from a neighbouring height *d*, composed of large blocks of the subja-

Fig. 77.

cent rock *c;* so that the block *a*, though it rests upon a rock differing from it, *b*, is not erratic, in the sense the term is usually employed by geologists. If, however, he finds, as in the annexed section (Fig. 78), where, for the

Fig. 78.

sake of illustration, *a b* represents a horizontal distance of twenty miles, blocks of granite resting in various situations, *c, d, e*, upon rocks, *h, h, h*, which are not granitic, there being no doubt that they could not be derived in the manner above noticed, then an observer has erratic blocks, properly so called, before him.   In the above section (Fig. 78), we have supposed similar granite to that of which the erratic blocks *c, d, e*, are composed to occur in place at *f;* so that it may be concluded that the erratic blocks were derived from *f*, and now occupy their relative positions from some transporting cause.

b. We have above considered the erratic blocks to be formed of granite. It must not, however, be supposed that an erratic block is necessarily composed of that rock. Any block of rock, no matter what the composition of it may be, if it occur on another different from itself, and has not fallen from a neighbouring height by the mere effects of unequal decomposition, gravity, and rain, is an erratic block. It is obviously of importance that an observer should correctly note the composition of any erratic block, so that he may be enabled to trace it to the mass of which it once constituted a portion. When blocks of various kinds are mingled in a heap before him, he should carefully estimate the relative proportion of each kind, so that, in tracing them to their sources, he may duly appreciate the direction and amount of the forces which have thrown them into one heap.

c. As it is difficult to conceive any other power than that of moving water to have transported erratic blocks into the positions where we now find them, we should expect, if they were hurried onwards in a body, and violently thrown against each other, that they would be rounded in proportion to the respective distances they have travelled. If they have been merely ice-borne upon floating and detached portions of glaciers, they may evidently have been carried considerable distances without exhibiting any other marks of friction than those which they may have experienced when falling originally on a glacier, or when brought to rest. Observations, therefore, on the angular or rounded characters of erratic blocks are essential, as also on their volume and weight ; so that, when we come to calcu-

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late the forces required to transport them, we may have good data for so doing. To ascertain the approximative volume or size of a block, an observer must evidently take some care, allowing for inequalities and any portion embedded in the soil. To obtain its weight, he must detach specimens which afford an average of the general structure, and ascertain the specific gravity of his specimens; after which the weight is readily calculated, the volume of the block being known.*

d. It having been found that the erratic blocks scattered on each side of the Alps diminish in volume and become more rounded as they recede from the central chain whence they were derived, an observer, if he discover erratic blocks on either side of a mountain-chain in any other part of the world, should direct his attention to this circumstance. As, in the Alps, ranges of erratic blocks are sometimes observable in a line some height above the bottom of a principal valley, through which they have evidently descended, this circumstance also should not be neglected. If the annexed sketch (Fig. 79) represent a principal Alpine valley, then a line of erratic blocks sometimes occurs as at *a*, while accumulations are occasionally found behind an elevation which is open to the line of valley, such as *b*, and where we may consider that an eddy would be produced if a considerable volume of water suddenly descended the valley. An observer should also direct his attention

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* Suppose an observer finds the specific gravity of the rock to be 2·66 ; then as a cubic inch of distilled water weighs 252·458 grains, 252·458 × 2·66=6715·383 grains, the weight of a cubic inch of the rock. Having ascertained the weight of a cubic inch of any rock, that of any number of cubic feet can of course be readily obtained.

to any face of a mountain which may arrest the progress of such a volume of water in its passage down the valley, and see whether erratic blocks are there collected ; and if so, whether they occur mixed pell-mell of all sizes, down to mere gravel.

Fig. 79.

e. Over extensive tracts of comparatively level country where erratic blocks occur, an observer should endeavour to trace the lines which the various kinds of rocks may have travelled.   He can in some manner accomplish this by adopting particular colours for the different rocks, and marking on a map, by such colours, the lines on which he discovers such rocks.   If the courses of that multitude of erratic blocks which occurs in Northern Europe and America were thus traced, even approximatively, much valuable information would be obtained. If this were done, we should find many colours

running short distances up to the parent rocks whence
the blocks were derived, while others would extend
across considerable areas. Some lines, though often
curved in the small scale, would take given directions
on the large ; while many smaller lines would follow
various directions.

f. It is important to note the relative age of the
rock upon which erratic blocks rest, if the observer be
sufficiently versed in geology : if not, he should care-
fully detach specimens from it, — ascertain whether it
contains organic remains or not : if it does, he should
collect as many of them as he can ; mark whether the
beds, should the rock be stratified, are horizontal or
not ; and, above all, he should examine whether there
are any evidences of the block having been encased in
sands, marl, or clay, which having been removed by
surface causes, has left the block exposed. It is consi-
dered that the blocks generally are superficial, and have
not been covered by any body of transported matter,
constituting a bed covering a large area, and to which
some name, marking a particular geological epoch, has
been assigned. It is therefore particularly necessary to
pay attention to this point.

g. The observations on erratic gravel should be much
the same as on erratic blocks. Great care should be
taken to examine the kind of pebbles of which any
mass of gravel covering an extensive district may be
composed. It is obviously important duly to appre-
ciate the causes which have produced their transport :
whether they have been gradually detached from their
parent rocks, and slowly transported by the aid of
rivers or other aqueous agents, now daily in force, or

whether we must look to any more general action of
moving water passing in greater volume over the land.
When accumulations of gravel are only composed of
pebbles that may have been carried down the valley
in or at the termination of which they are found, the
size, shape, and weight of the pebbles should be taken
into account, and a fair estimate made of the power of
the waters, now descending the valley, to carry them
down, proper allowance being made for the slope of the
river-channel, and the accumulative power of floods
during a succession of ages.   It should also be seen
whether pebble-beds are, such as the celebrated Crau
district (France), mere terminations of a great wash of
erratic blocks.   In some situations, gravels of different
kinds rest upon each other ; one having been formed
by the action of rivers, another probably from the pas-
sage of a larger body of water :—this should receive
careful attention.   Again, though gravel-beds may ap-
pear superficial at one place, they may be only lower
portions of a series of rocks, which can be traced be-
neath many others in another ; a conglomerate bed
having been weathered, the cementing matter removed
and the pebbles left.   It is necessary, therefore, that
the observer pay attention to this circumstance.

  XVIII. *Ossiferous caverns and osseous breccia.*—
Ossiferous caverns are caves so named because in
them the remains of various animals, such as bears,
hyenas, elephants, &c. are detected, often enveloped
by mud or other deposits, and in such cases concealed
from ordinary observation. Osseous breccias are for the
most part clefts of rocks, such as have been previously
noticed (p. 110), filled with bones, fragments of rocks,

and an earthy or compact cement. They are some-
times connected with ossiferous caverns.

   a. An observer after entering a cavern may again
return from it without the slightest suspicion that it is
ossiferous, and yet the cave contain the abundant re-
mains of animals. Many in our own country, which
have furnished hundreds of bones and teeth of various
mammiferous creatures to those who properly searched
for them, have been visited from time immemorial by
numbers who never observed a trace of such exuviæ.
Caverns are far more abundant in limestone rocks than
in others; and hence the frequent occurrence of stalac-
tital and stalagmitical matter in ossiferous caves, which
often masks the organic riches contained beneath it.
The conditions of ossiferous caverns vary; but the an-
nexed section (Fig. 80) may serve to illustrate one

Fig. 80.
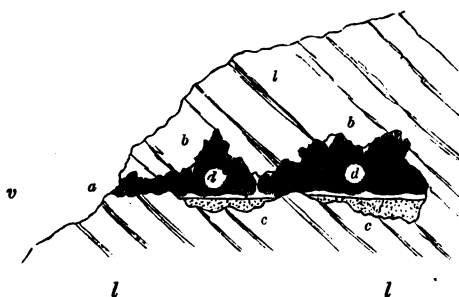
kind by no means relatively uncommon. Let *l l l* be
a section of a limestone hill, in which there is a cavern,
b b, communicating with a valley, *v,* by the entrance *a.*
Let *d d* be a floor of stalagmite (a deposition of calca-

reous matter formed by droppings of water, containing
carbonate of lime, from the roof), covering cavities, *c c*,
in which there is an accumulation up to the stalagmite,
d d, of the remains of animals, intermingled with mud,
silt, sands, or gravel, as the case may be. It will be
evident that an observer may pass in and out of such a
cavern, treading on the stalagmite floor, *d d*, without
being aware that the remains of animals are concealed
beneath.

b. In some ossiferous caverns there has been a depo-
sition of stalagmitic matter upon the bottom of the
cave before any mud was introduced into it, and bones
are often found sticking in the former : in fact, the
latter have been covered over by the stalagmite as it
formed. In other caverns, the mud, sand, or gravel of
the bottom in which the bones occur is uncovered by
stalagmite of any kind. In this respect there is con-
siderable variation, as must happen from differences of
local conditions, and of the manner in which the bones
were introduced into the cavern.

c. When an observer discovers bones in a cavern, he
should pay particular attention to their mode of occur-
rence. Let him make a complete section of the stalag-
mite, mud, silt, sands, or gravel, as the case may be,
noting the depth of each different bed, and carefully abs-
tract specimens from each before fragments of it become
mingled with the others. He must be careful to mark
whether different kinds of bones or teeth occur in par-
ticular beds, or are all mingled together. He should
also make different sections of the cave at various
points, particularly noting where or in what directions
it may communicate with the surface ; for caverns fre-

quently lead to the surface in other places than their
entrances, such being filled with fallen rubbish.   It is
particularly important to remark whether such commu-
nications are vertical or nearly vertical, so that they
may have been open fissures before they were stopped
up with the fallen rubbish.

    d. An observer should be particularly careful in as-
certaining the general external conditions of the situa-
tion where the cavern occurs; noting whether it was
ever probable that it was concealed by gravel or angu-
lar fragments of rock, which having been subsequently
removed by natural or artificial causes, a free entrance
into the cavern was obtained.   The celebrated Kirk-
dale cavern, which drew so much public interest to this
subject, and which Professor Buckland showed to have
been the den of an extinct species of hyena, that drag-
ged into it the remains of extinct elephants, rhinoceroses,
hippopotami, and other creatures, then inhabitants of
Yorkshire, was closed by a covering of gravel, and was
accidentally laid open by quarrying.   If a cavern has
remained open to the surface during long .periods up
to the present time, it may have been tenanted first by
creatures now extinct, and subsequently by those now
existing ; and hence their various remains may be de-
tected in it, sometimes mixed, at others in beds above
each other.   Consequently, the remains of man and his
works may be discovered in such places, as has been the
case, particularly in the South of France.

    e. To ascertain whence any mud, silt, sand, or gravel
may be derived which is mixed with the bones, or occurs
in beds above or beneath them, an observer must study
the position of the caves, as regards the physical struc-

ture of the neighbouring country. Let, for the sake of illustration, the annexed woodcut (Fig. 81) represent

Fig. 81.

the section of a valley, on one side of which there are two ossiferous caverns, *a* and *b;* and let a river, *r*, running in the valley, be of sufficient size to bring down mud, sands, and gravel, according to the abundance of water in it ;—it will be obvious that, from the position of the cavern *b*, such detrital matter might be carried during floods into it, and envelope or cover any bones lying in the places to which the water could find access : the waters might even surprise and drown living animals in the cavern. No such effects could be produced by the same cause in the cavern *a*. The observer will now see the importance of having collected specimens of the mud, sands, or gravel in ossiferous caverns : he can readily compare such substances with any alluvial matter brought down by a neighbouring river, and hence see any difference or resemblance between them. If pebbles be detected in these caverns, which could not have been derived by the actual rivers from the situations that could have furnished them, we must look to other causes for their presence in the caverns. And in this way, a variety of inferences may be drawn as to the

different circumstances which have attended the preser-
vation of the bones of animals in different ossiferous
caverns.

f. We have remarked, that observations respecting
any vertical or nearly vertical communication of an
ossiferous cavern with the surface is important. It is
so, because we may then have a large accumulation of
the bones of creatures which have fallen over the edges
of the fissure while open. Let the annexed woodcut
(Fig. 82) represent the section of part of a hill, in
which there is a cavern, *a a*, communicating with the

Fig. 82.
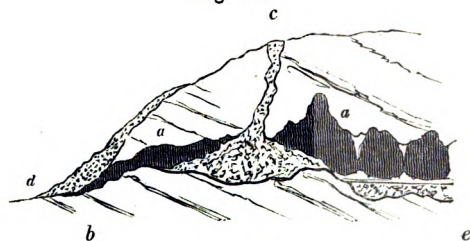
side of the hill at *b*, and with its summit by a fissure,
c. This may have been a den of hyenas in the first
instance; and the creatures which fell down the fissure
c, would be consumed by them, leaving part of their
bones; so that there might be an accumulation of bones
of the hyenas and of their prey in the inmost recesses
of the cavern *e*. We can readily imagine that, from
the decomposition of the rock forming the hill, detrital
rubbish could eventually so accumulate at the entrance
of the cave as to close it at *d*, so that it was no longer
tenanted by its old inhabitants; or supposing these able
to keep the entrance open, when the time came for their

extinction, that it became closed, leaving the perpendicular fissure open. Now, if animals still continued to fall through the latter into the cavity beneath, there would be an accumulation of their remains, the bones which the hyenas formerly consumed remaining, injured only from the fall of the animals. Thus there may be two accumulations of animal exuviæ in the same cave, one having been effected under different circumstances from the other, the species even of the creatures which fell through the fissure being perhaps different; and yet to a careless observer the whole might appear one mass of mixed bones, fragments of rock and earth, introduced into the cavern through a lateral aperture; the perpendicular fissure having been gradually filled with fragments of rock, earth, and perhaps some animal remains. We merely notice such possible combinations of conditions to show the reader the necessity of correct observation, particularly when the bones of man are found mingled with the bones of animals under equivocal circumstances.

g. The transition of such a cavern as that last noticed into a cleft filled with osseous breccia is slight. Let the annexed sketch (Fig. 83) represent the face of

Fig. 83.
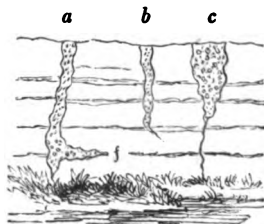
a natural or artificial cliff, exhibiting clefts, *a, b, c,* filled
with a mixture of bones, earthy matter more or less
indurated, and fragments of the adjoining rocks.   It
will readily be seen that they are in the condition of
the open fissure *c* (Fig. 82).   Sometimes there is a
little offset from the main fissure, as at *f* (Fig. 83),
—a kind of minor lateral cave.   Having previously no-
ticed more modern fissures of this kind (p. 110), we
now merely call attention to the red calcareous cement
so commonly detected in them, and which varies in its
state of induration from an earthy to a very compact
substance.   From this circumstance, as M. de Cristol
has observed, it has been too hastily concluded that all
osseous breccias are of the same age, though they pro-
bably differ materially in this respect.   The same au-
thor suggests,* that the red cement is but the red
earth arising from the decomposition of the limestone
in clefts of which the osseous breccia is found ; and ob-
serves, that in all cases where the red cement occurs, the
cleft is in limestone, or where matter may be washed
from limestone.   As far as our personal observations
extend on the osseous breccias of Italy and Southern
France, this opinion perfectly accords with facts.   This
red substance is considered to be washed by rains into
the clefts and upon the bones ; which latter continue
to accumulate, and are thus eventually cemented to-
gether by the red substance, that becomes compact
when carbonate of lime is introduced by aqueous infil-
tration among its particles.

   h. There is another cause which may produce a mix-

   * " Observations Générales sur les Brèches Osseuses:" Mont-
pellier, 1834.

ture of the bones of various animals with fragments of
rock, earth, and even pebbles derived from a distance,
which an observer should bear in mind while examining
an ossiferous cavern and the country around it.   In
some limestone countries, small rivers lose themselves in
cavities, and, after running through a series of subter-
ranean caverns, reappear on the surface at various dis-
tances from the spot where they first entered the subter-
raneous passage : it will follow, that they sweep into
such caverns a great variety of organic and inorganic
substances ; and that the passage being sometimes
closed by their accumulation, and the waters discharg-
ing themselves in other directions, such caverns, when
explored, might be ossiferous, and rounded pebbles be
mixed with the bones.   Let the annexed diagram
(Fig. 84) represent the section of a portion of country,

Fig. 84.
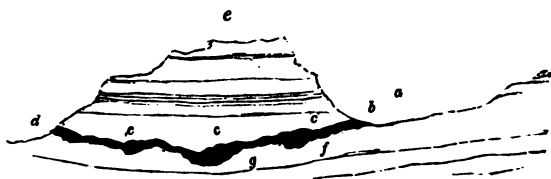
in which there is a depression, *a*, the lowest part of an
area, which would become a lake if the waters did not
find a subterranean passage beneath the hill or moun-
tain, *e*, from *b* on the one side to *d* on the other, by the
series of caverns *c c c*.   It will be obvious, that the in-
organic and organic substances, washed into the aperture
b, will be first lodged in the depression *f*, and subse-
quently in the depression *g*.   For the sake of illustra-

tion, we have made the series of caverns rise from *g* to the discharging aperture *d*.   In such a case, the constantly accumulating remains of animals, pebbles, sand, and earth, mixed with fragments of rock forming the hill, would probably stop up the passage between *f* and *d*, so that either the waters would form a lake at *a*, or find some other passage for themselves.   The reader can readily imagine a variety of modifying circumstances ; such as a change in the physical features of the country before or after the aperture became closed, mixtures of bones and rocks produced by other causes, and the like.

XIX.   *Dip and strike of strata.*—Before we enter upon directions for observing rocks of an older date than those now forming, it will be necessary to call attention to the dip and strike of those which are divided into strata or beds.

a. The dip is the angle which the plane of the strata or beds makes with the horizon.   To illustrate this, let the annexed sketch (Fig. 85) represent a table, *b*, on

Fig. 85.
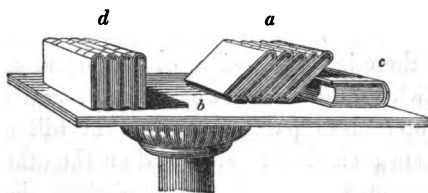
which some books, *a*, are made to rest in a slanting position by the support of another book, *c*, laid flat on

the table.   If now we consider the top of the table to represent a horizontal plane, and the books beds of rock, then the angle which the sides of the tilted books, *a*, makes with the table, *b*, would be called their dip, and according to the amount of the angle would be the amount of dip : that is, the less the sides of the books sloped, the less the dip ; and, conversely, the more up-right they were, the greater the dip.   The book resting flat upon the table would be said to be horizontal, and have no dip at all.   Let *d* be books standing upon the table with their backs upwards ; then strata or beds of rock which occur in a similar position would be termed perpendicular or vertical.

b. The strike or direction of beds or strata is a line at right angles with their dip.   The lines which the backs of the books *a* and *d* (Fig. 85) would take to-wards the north, south, or other points, as the case may be, would be termed their strike or direction.   Let us suppose that the books *a* dip to the west, then the lines of their backs would run north and south, which would be termed their strike or direction.   Let us fur-ther suppose that the backs of the books *d* are arranged parallel to those of the books *a* ; then the strike or direction of any beds of rock, situated as *d* and *a* are, would be the same, notwithstanding the beds at *d* would be vertical, while those at *a* would have a dip.

c. If strata or beds were always as regularly arranged with regard to each other as the books above noticed, or that the thickness of a bed were always as uniform as that of any given book, observations on the dip and strike of strata would be comparatively easy.   It would be merely necessary to contrive some instrument

which should rest upon the face of a bed, and which should, by the aid of levels or a plumb line, show the angle that such face made with the horizon, to obtain the true dip ; while a compass should show the point to which the bed dips, and would consequently give its strike or direction at right angles to it.   Accordingly, instruments of this kind, named clinometers, have been contrived, and much ingenuity has been exhibited in their construction ; but, in practice, there is not one situation in a hundred where they will be found to afford the least assistance.

Beds of rock, taken generally, afford surfaces which, viewed on the small scale, are rough and uneven, while on the large they may be considered to constitute planes that, when compared with the horizon, are either horizontal, dip at some angle, or are vertical.   It hence becomes necessary to employ some instrument which is not placed on the uneven surface of a bed, but which, when held in the hand, or placed on some convenient stand, should afford the requisite information, at least in a fair approximative manner ;—one, in fact,

Fig. 86.
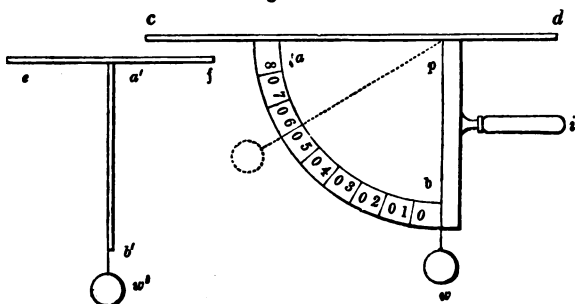
which, by massing small irregularities, should afford a general plane that can be compared with that of the horizon. For this purpose we have found an instrument, represented in the annexed sketch (Fig. 86), extremely useful in practice. It consists of a graduated quadrant, *a b*, of platinum, silver, or brass, fitted in its upper part into a rectangular plate of metal, *c d*, having a polished upper surface, the proportion of the length to the breadth being as *c d* to *e f*. The quadrant is connected at *b* by a strip of metal fixed perpendicularly to the under surface of the plate *c d*; and from this portion projects a small ivory or ebony handle, *i*. It will be evident, if from this instrument we suspend a metal weight, *w*, by a fine hair, or other convenient substance, from the point *p*, which is the centre of a circle of which *a b* is a quadrant, and the instrument be so adjusted that when properly held by the handle *i*, the hair and weight, *w*, shall just graze the instrument, while the former cuts the zero of graduation, that the plane *c d* will be parallel to that of the horizon. Hence, if looking along the plane on the top of the instrument we find it coincide with that of a bed of rock under examination, we learn that the latter is horizontal,—at least the observation would be sufficiently correct for ordinary geological purposes.*

Let an observer have before him a range of beds or strata that are evidently neither horizontal nor perpendicular, the dip of which he is desirous to ascertain; by inclining the plate *c d*, so that its plane shall coincide with the general plane of the rocks before him,

* *a′*, *b′*, *w′*, show the quadrant *a b*, and the weight *w*, as seen from behind, the handle of the instrument being removed.

K

and allowing the hair, with the weight *w* attached, just
to graze the graduated quadrant *a b*, the line of hair
will cut the graduation at some point. The difference in
degrees between this point and the zero of graduation
will give him the dip of the beds of rock, or the angle
which they make with the horizontal plane. If it
be required that the surface of the plate *c d* should be
so inclined that the hair, when held perpendicularly
strained by the weight *w*, cut the graduation at 60°,
then the dip of the rock would be 60° in some direc-
tion which remains to be ascertained.

Now, if the instrument has been properly held in the
plane of dip, the direction of the longest sides of the
upper plate will coincide with that of the dip. It re-
mains, therefore, carefully to find this direction by a
good pocket-compass, making proper allowance for va-
riation from the true north ; and the observer has the
amount and direction of the dip required, and hence
the strike or direction of the same beds. A little prac-
tice will soon render an observer sufficiently expert with
this or any other instrument contrived upon similar
principles. We should particularly insist on the neces-
sity of making such observations with reference to the
true, not the magnetic, north, in consequence of the
errors that may arise from the shifting character of the
latter.

d. In the foregoing observations we have supposed
that the beds to be examined were so exposed, naturally
or artificially, that an observer could readily obtain a
true general view of their planes of stratification. This,
however, is far from being always the case. It often
happens, as for instance in the face of cliffs, that the

sections of beds offer mere lines. It will be obvious
that these lines, viewed only in one sectional surface,
may afford an incorrect idea of the true position of the
beds.   Let the annexed sketch (Fig. 87) be a view

Fig. 87.
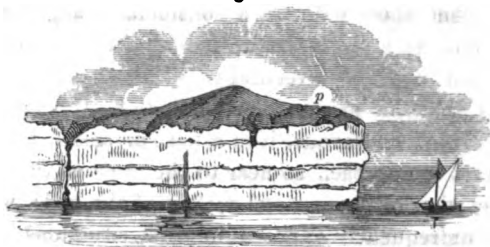
of a headland from the south, in which some beds of
rock appear to be arranged horizontally.   Should an
observer, in such a case as this, be unable to see the
surfaces or planes of the beds, he should hesitate in con-
sidering the beds in question as really horizontal: he
should endeavour to obtain some sectional view in an-
other direction.   Let us suppose, for the sake of illus-
tration, that the headland noticed above trends away

Fig. 88.

κ 2
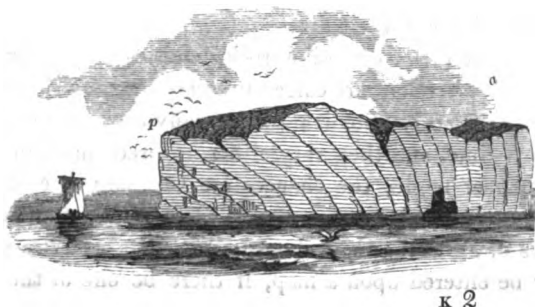
at the point *p* to the northward, affording the cliff-
section annexed (Fig. 88), which is exposed to the
eastward. In this instance the horizontal appearance
of the beds when viewed from the southward is evi-
dently deceptive, for the lines on the eastern side of
the headland show a dip at a considerable angle to the
north, and such lines, by a gradual curvature of the
strata, finally exhibit a vertical character at *a* (Fig. 88).

e. When cliffs are under examination, the observer
should always endeavour, if in a boat or vessel, to land,
or at least to approach so near to the coast as to obtain
a correct view of the general surface of the beds, which
are not unfrequently exposed in such situations. In-
deed there are few situations so proper for obtaining
the dip and direction of beds correctly as coasts, parti-
cularly when washed by tidal seas. Large masses of
rock rising through the sea, and which are exposed to
the fury of the breakers during gales of wind, are parti-
cularly favourable for such observations. The above
remarks are equally applicable to the apparent lines of
stratification exhibited in inaccessible cliffs among moun-
tains, where it is alike necessary to have more than one
sectional view of the beds before we can even judge ap-
proximatively of their dip.

f. When the dip of a rock, and consequently its
strike or direction, are correctly ascertained, an observer
should instantly note it; for if many dips be taken in
a short time, and they vary either in direction or in the
amount of angle, the chances are that he will commit
some error when he commits them to paper at the end
of his day's work. We should also strongly advise that
they be entered upon a map, if there be one of the lo-

cality or district examined, at the time of observation;
for by so doing accuracy is ensured, and the observer,
as he advances in his work, gradually perceives the stra-
tification of the country unfolding itself before him by
mere reference to his map.   We have found the follow-
ing signs (Fig. 89) extremely useful for the purpose

Fig. 89.
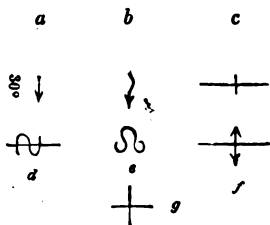
of reference.   The arrow, expressing the dip and point-
ing to its direction, has long been in use : *a* shows the
direction of the dip, the head of the arrow pointing to
it.   If the bottom of this page represent the south part
of a map, then the dip of a rock marked by *a* would be
to the south.   The angle at which a rock dips can be
conveniently marked on the side of the arrow : thus *a*
would be the dip of a rock to the south at an angle of
30°.—*b* shows that while the strata undulate on the
small scale, they dip as a mass in the direction of the
point of the arrow *b* ; *c* represents perpendicular strata,
the longest line showing the strike of the beds ; *d* ex-
hibits strata which, while they are contorted in such a
manner as to show no given dip, have still a marked
strike, represented by the straight line ; *e* shows strata
which are so contorted that complete confusion is exhi-
bited, and therefore neither dip nor strike can be repre-

sented ; *f* is a sign for an anticlinal line, or one from which strata dip on either side ;—(the ridge of a house-top will convey an idea of an anticlinal line, the slopes of the roof representing the dip of the beds on either side;)—*g* is a cross formed by the intersection of two equal straight lines, and is a sign for horizontal strata.

g. It has often been supposed that the division of rocks into beds is characteristic of those deposited from water, in which the matter composing them was either in chemical solution or mechanically suspended. This, however, is not strictly true, inasmuch as tabular masses of basalt, trachyte, and their respective conglomerates, do cover each other over areas of various magnitudes : hence the above-noticed signs should be equally applied to any rock that is divided into beds, whether they be considered of aqueous or igneous origin. The object sought by means of these signs is simply to mark upon paper that the rocks of given localities, if they be divided into beds, either dip in a particular direction, have a certain strike, are contorted, or the like, without reference to their supposed origin. In general, however, rocks of an igneous origin occur in masses. To show this on geological maps, though it has not, we believe, yet been done, is evidently useful. For this purpose we should recommend the annexed signs (Fig. 90), in which *a* represents the occurrence of a rock in mass. Igneous rocks are sometimes also columnar ; indeed this structure is sufficiently common in some, such as basalt : this character can be represented by the sign *b* (Fig. 90).

Fig. 90.

XX. *Faults and contorted strata.*—There are few things which require more constant attention on the part of a geological observer, than the errors into which he may inadvertently fall from inattention to those dislocations of strata, technically termed *faults*, which so frequently occur.   Attention also to contortions is equally necessary.   From the amount of contortion we may in some measure infer the intensity of the force required to produce it; and from the kind of rocks so bent and twisted, we may ultimately learn the conditions necessary for such contortions.

a. It has been by no means an unfrequent practice, in constructing geological maps, to ascertain the strike of a series of rocks, and then cross the country in lines at right angles to this strike, such lines being occasionally at a considerable distance from each other.   We have found this plan particularly liable to error, lines of dislocation or faults being thus wholly overlooked.   It is necessary that a geologist should cover the country, if we may use the expression, with a net-work of observations, to ensure accuracy, not only in this, but in other points.

b. It will be obvious that faults will be apparent in proportion to the general stratification or character of the rocks in which they occur.   It will be very difficult to ascertain, by mere surface inspection in the interior of a country, that a rock, stratified vertically, has sustained any perpendicular movement of elevation or depression, or that a rock in horizontal stratification has sustained any horizontal movement; for in both instances similar rocks will adjoin similar, and hence the dislocation be difficult of detection.   Let the annexed

sketch (Fig. 91) represent a map of a portion of

Fig. 91.
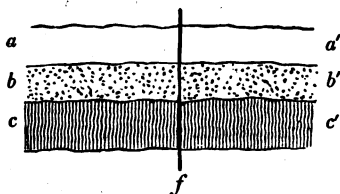
country composed of three rocks, *a*, *b*, *c*, the beds of
which are vertical; it will be obvious that if they be
traversed by a fault, *f*, which lets down the beds per-
pendicularly, *a'*, *b'*, *c'*, on the one side, will abut against
a, *b*, *c*, on the other, and therefore the presence of the
fault be unnoticed. If the sketch (Fig. 91) be now
considered as a section instead of a map, it will be
equally clear that a horizontal movement will always
bring like beds against each other. Under such cir-
cumstances, an observer will often find lines of consider-
able springs of use to him, since they frequently burst
out in lines of fault. He should particularly direct his
attention to patches of broken ground and cliffs in the
suspected line of fault, and there search for marks of
dislocation.

   c. Having ascertained the existence of a fault, which
is often sufficiently apparent in sea-cliffs, or in situa-
tions where rocks of different mineralogical characters
come suddenly in contact, an observer should endea-
vour to ascertain whether the sides of the fault are in
close contact or not. He should carefully search for
any traces of friction which may have polished or marked
with lines the surfaces of the sides, noting if the lines

seem to coincide with the supposed direction of the
dislocation.   When the sides of a fault do not abso-
lutely touch, as in the annexed section (Fig. 92), he

Fig. 92.
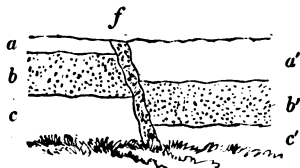
should examine the substances, commonly termed the
contents of the fault, found between the surfaces of the
fault.   The contents of the fault f may be either de-
rived from the rocks a, b, c, or from some other sources.
If there has been much grinding of the sides of the
fault before they ultimately settled in their present
relative situations, the fragments may have been more
or less crushed and pulverised.   If the fault has gaped
from the commencement, the fragments would fall from
their own gravity, and therefore we should expect that
fragments of the rock c would not be found above b
(Fig. 92).

d. An observer should particularly attend to the di-
rection of a fault, taking its general bearing as respects
the true north, east, west, or south, as the case may be;
and while he carefully notes the deviations from its prin-
cipal line of direction, he should endeavour to trace the
range of the fault as far as possible, in order to ascertain
what should be considered its true line of bearing.
Let a b (Fig. 93) represent the range of a fault for
twenty miles, and let the top and bottom of the page
correspond respectively with the north and south parts

K 5

Fig. 93.

of a map; then the range of the fault *a b* will be east
and west, notwithstanding its subordinate deviations
from that direction.   It will be obvious that, if two or
three miles only of the fault be traced at parts interme-
diate between the points *a* and *b*, the fault might be
considered to have other directions.   Hence the neces-
sity of tracing faults to comparatively considerable dis-
tances when practicable.

   When many faults occur in a district, it is always
desirable to ascertain how far they may be parallel to
each other.   In such cases, as in the direction of any
one fault, the general range should be attended to, in-
stead of the directions of minor parts.   Let *c d* (Fig. 93)
represent a fault, also about twenty miles long, occurring
in the same district with the fault *a b;* then these two
faults may be considered parallel to each other, notwith-
standing there is scarcely two or three miles of any
given portion of each which are strictly parallel.   It
will be obvious, that in laying such faults down on
maps, the scale of the latter may either be so large as
to show numerous subordinate directions, or so small as
almost to convert them into nearly straight lines.   We
have, for the sake of illustration, supposed the faults to
be about twenty miles in length.   Now, if we imagine
the fault to range to a far greater distance, it may so
happen that the direction attributed to this line of fault
may not be the true one, upon the same principle that

several minor portions of *a b* and *c d* would not give their true directions.   When faults are traced only for about a mile in length, it will frequently require much hesitation on the part of the observer before he states that the range of the whole fault is in any given direction.   If the line of fault be laid down on a map for the distance observed, no error can arise, since such line, if correct, will merely represent a matter of fact, and others will be enabled to judge of the inferences which may be deduced from it; but when words only are employed, the case is different.   If only told that a fault has a given range, without being informed that the same fault has been only traced for a short distance, we may be misled, since the direction given may not be that of the fault when traced through greater distances.

e. The observer has strictly to attend to the amount of vertical dislocation in a fault; that is, the distance to which the broken and once continuous rocks have been forced from each other vertically. To obtain this amount of dislocation correctly, requires care,—more, perhaps, than is often taken.   If the beds be horizontal, as in the annexed section (Fig. 94), and the fracture *f* be verti-
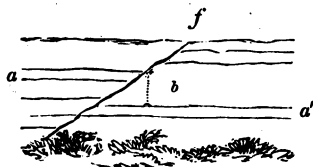
Fig. 94.
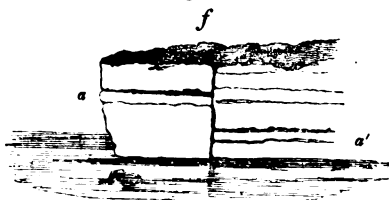
cal, then the distance of the marked bed *a* on the one

side from *a'* on the other, measured perpendicularly,
will give the amount of dislocation. If, however, the
fracture be not vertical, but slanting, while the beds
themselves retain their horizontality, as in the annexed
section (Fig. 95), in which the same letters represent

Fig. 95.

the same things as in the previous section (Fig. 94),
then the distance measured down the line of fracture
would not give the amount of dislocation, as will be
seen by comparing the two sections (Figs. 94, 95) to-
gether, for we have purposely represented the amount
of vertical dislocation equal in both. To ascertain the
amount of dislocation, it will be necessary to drop a per-
pendicular line, *b*, from the end of the upper part of the
dislocated bed, where it abuts against the fault, and the
distance from the dislocated portions of the bed so mea-
sured will be the distance required.

f. The observer will readily perceive that strata may
occur, relatively to fractures and faults, in such a manner
that to obtain a correct estimate of the amount of dislo-
cation in such cases will require much attention. We
must leave him to exercise his own skill and ingenuity
in obtaining the object sought in such cases; for it
would be occupying too much space to advance hints
for the various complicated arrangements of fractures and
beds which may occur.

g. We may here call the attention of the observer to those larger dislocations of rocks which constitute mountain masses, and which, having been squeezed up against each other more in certain directions than in others, have given rise to the lines of elevated land commonly termed ranges or chains of mountains. Such dislocations are but faults on a larger scale than those so frequently seen in more level countries. The masses broken are larger, the lines of fracture longer, and the amount of vertical dislocation more considerable. They are, however, mere cracks on the earth's surface ; and their relative importance will be better understood by the observer, if he take a common artificial globe in his hands, measure the comparative length of a chain of mountains upon it, and estimate its height as compared with the diameter of such a globe, than if he listen only to those descriptions, which, however beautiful they may be, are still but deceptive, since they lead us from a true estimate of the relative importance of mountains as regards the earth's surface generally. If an observer be so embarrassed among mountain scenery that he measures all around him by his own relative magnitude, and loses a general view of the cracks and disjointed masses of rock, regarded only as such, in the imaginary magnitude of surrounding objects, he is not likely to advance this portion of our subject. Let us not be thought to underrate the value of mountain scenery. We should be ungrateful if we did so ; since our happiest moments have been passed amid glaciers, torrents, and ravines, our feelings excited and ·our thoughts occupied by little else than the scenes around us. An observer may readily be both geologist and

artist ; but when he views nature as the former, he must, for the time at least, place the artist aside, and consider mountains as mere dislocated masses of rock, thrown up in lines, and forming relatively minute ridges and depressions on the superficies of our globe.

 . *h.* The directions given for observing the smaller dislocations of rocks will apply also to the larger : the means for obtaining the measurements of the distances which any mass may be moved on either side of a great fault will necessarily be more complicated than those employed for observing a small fault.   Having noted the dips, if any, of the rocks, the amount of vertical dislocation seen on the sides of mountains, or on the two sides of a valley, must be obtained trigonometrically, or by aid of the barometer. The horizontal amount of movement must be sought trigonometrically in the usual manner.   As the lines of fracture or fault in mountain chains are important in determining the value which should be attributed to given directions of fracture, prevailing at given epochs of their elevation, great care should be taken to determine this point ; the observer duly considering that general lines of direction are sought, and hence that minor and subordinate directions of a great line of fracture should not be confounded with them, as has been noticed above in the case of smaller faults.

 . *i.* When an observer finds himself among contorted strata, he should endeavour to see whether the beds, notwithstanding their contortions, have a given strike, as is often the case.   Let the lines of this page represent the strike of the beds ; then the reader will have no difficulty in considering that the paper, supposed to

represent some given bed, can be plaited and crumpled
in such a manner that the lines of print can be made
to form the tops or bottoms of contortions having a
given direction or strike, the ridges of the contortions
being parallel to each other. If now, when a piece of
paper is plaited or crumpled up in this manner, we,
as it were, plane off a piece of the upper surface, we
shall obtain a series of cut edges of paper all parallel,
or nearly so, to each other.   Let the annexed diagram
(Fig. 96) represent the end view of several pieces of

Fig. 96.

paper or cloth plaited or crumpled up in parallel ridges:
if we now consider these pieces of crumpled paper or
cloth to represent a series of rocks contorted in the same
manner, that *a b* is the sea-level, and *c d* an outline of
several hills, we should, in those parts of the figure
which are not dotted, obtain a view which may be observ-
ed on several coasts, such, for instance, as that extending
from Hartland Point (North Devon) to the southward.

k. It will be obvious that, in a district of contorted
strata, the general plain of dry land may so cut the
contortions that there may be numerous bosses of in-
ferior beds rising through superior; while the latter
may be depressed in basin-shaped cavities of the former.
If it should so happen that abrading surface-causes act
upon beds raised upwards, in such a manner that they
are worn away in a basin-shaped cavity, then the result-
ing depression is termed a circus, or circular valley of

elevation. Let the annexed sketch (Fig. 97) represent

Fig. 97.
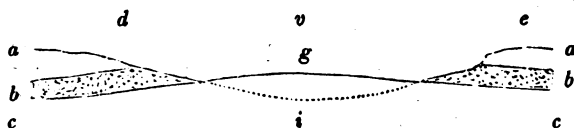
a section of a protrusion of beds, from contortions or
flexure of the strata, by which *a*, *b*, *c*, are raised upwards
at *g* ; and that *c* is a rock which has better resisted sur-
face abrasion than *a* and *b* ; then the depression *v* would
be termed a circus of elevation, if the escarpments *d* and
e formed a kind of circular or oval range of high land
around the depression *v*, with probably some outlet for
the general drainage of the waters, flowing into or falling
upon the depression. We have supposed, for the sake of
illustration, that the rock *c* had resisted surface abrading
action sufficiently to rise upwards, in a kind of minor
hill, in the central part of the depression, because this
not unfrequently happens in such cases. The same
figure may be made to illustrate valleys of elevation,
by taking the dotted line *i* for the bottom of the valley ;
so that *d* and *e* are hills on either side. In this latter
case, we suppose the rock *c* to have been abraded and
worn down to *i*. It will be necessary for the observer
to ascertain, whether the valley is not a crack or fis-
sure so upheaved as to produce the outward dip from
the central line of valley, or a mere abraded contortion,
such as is given Fig. 97. Let the annexed section
(Fig. 98) represent a fissure in which the rocks *a*, *b*, *c*,
have been upheaved, so that when first broken the frac-

tured beds formed the gaping cavity d, f, e. If now the
fractured rocks be so worn down that the line g h re-

Fig. 98.
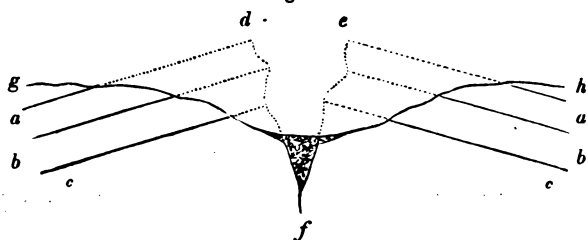
presents the actual surface of the country, the lines of
the beds might seem to give simple curves, broken into
by the abrasion of the land generally.   The observer
will therefore direct his attention to the central parts of
the valley, and note whether the rocks be continuous
across, or if such parts be filled with gravel, or other
detritus, to such depths as would render it probable
that the lower part of a fissure has been filled by it.
By noting carefully the amount of dip on either side
of the valley, and then by constructing a *proportional*
section of the whole valley—one in which the heights
and distances are on the same scale,—he will also be
enabled to judge how far either a great flexure or frac-
ture of the rocks may afford the most probable explana-
tion of the phenomena observed.

- **XXI.** *Cleavage of rocks.* — Rocks, both massive
and divided into beds, usually termed strata, are some-
times split in lines which are exceedingly deceptive,
inasmuch as they may be readily confounded by the
inexperienced observer with those of beds.   In fact,
many errors have arisen from inattention to cleavage.

a. Cleavage on the small scale may frequently be noticed among argillaceous slates. Let the annexed diagram (Fig. 99) represent the section of a cliff composed, with the exception of the bed *c,* of argillaceous

Fig. 99.

a   b   c   d   e   f   g   h

slate, and let the observer find two kinds of lines ; *a, b, d, e, f, g, h,* being those of planes which dip in one direction, while the laminæ of slate take another, as represented by the short lines in the figure. He may probably be embarrassed regarding the planes, which should be considered those of cleavage ; for he must by no means consider that the laminæ are always formed by cleavage, and that the planes of the larger masses are those of the beds or strata ; since we have seen several instances, in slate countries, where the laminæ of the slate were in the true planes of the beds, while the lines forming larger masses were those of cleavage. Where difficulties of this kind occur, the observer should carefully search for some interstratified bed of sandstone or other marked rock which shall give him the true direction of the beds. In the above diagram (Fig. 99) we have supposed such a bed to exist at *c,* which would show that the lines *a, b, c, d, e, f, g, h,* were those of stratification, and the lines of the laminæ those of cleavage. We have seen slate rocks divided in three directions by different planes, so that it required great caution in discovering which were those of cleavage. Among other places, this fact is readily observed near Morte

Point on the north coast of Devonshire.   One series
of planes dips northward, another southward, and a
third series traverses the others perpendicularly in north
and south directions.   Fortunately, some hard beds, at
no great distance, afford the true dip and direction of
the strata ; but, as this does not always happen, we
must particularly caution the observer to be on his
guard as to the dip and strike of beds in districts of
argillaceous slates, particularly when extensive natural
or artificial sections cannot be obtained.

   b. It sometimes happens, that the cleavage lines
traverse equally argillaceous slates and sandstone, or
other hard beds associated with them. In the grauwacke
group, this may not unfrequently be seen.   In these
cases the cleavage lines are more frequently perpen-
dicular to the general stratification than otherwise.
When they are not so, the observer can scarcely con-
found the lines of cleavage with those of stratification ;
since he will, by taking the lines which mark those of
similar substances,—such, for instance, as sandstones,—
readily ascertain the latter.   He might, however, when
the cleavage lines are perpendicular to the dip of the
beds, mistake them for those of faults.   In such cases,
it will be necessary for him to see whether there be
any dislocation, or merely lines which cut in given
directions downwards without deranging the relative
position of the beds.

   c. Cross cleavage in limestones of the dark-coloured
and compact kinds, such as those of the carboniferous
and grauwacke groups of England, are by no means un-
frequent, and require the observer's attention, since the
mineralogical character of numerous superimposed beds

is often the same ; so that when there is a want of organic remains, it is no easy matter to decide upon which are the true lines of stratification.   Let the annexed sketch (Fig. 100) represent an isolated rock of lime-

Fig. 100.
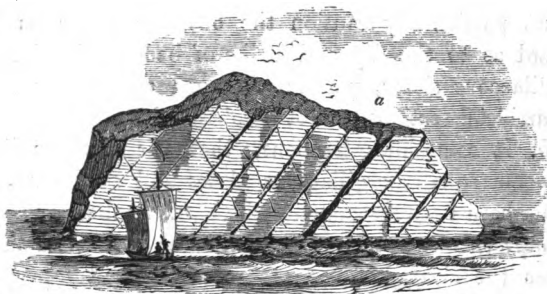
stone standing in the sea, and let two series of parallel lines cross each other as there represented.   The observer should, in such a case, search for some trace of a thin interstratified shale-bed which may afford him the true lines of dip and strike.   We have, for the sake of illustration, supposed such a bed to exist at *a.*   When such cannot be detected, he must endeavour to ascertain whether there is any appearance of a bed, differing from the rest, taking one direction more than another ; and he should especially seek for organic remains, since separate beds often contain marked accumulations of them.

Fig. 101.
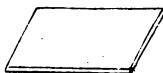
d. Among some compact sandstone rocks, particularly those of the age of the grauwacke group, beds will be found cleaved into rhomboidal prisms and other solids of the like kinds, such as that represented above (Fig. 101). The observer should see how far they generally resemble each other in the same beds, and how far their forms may differ according to their mineralogical structure. As the study of this cleavage on the small scale has as yet received little attention, it is desirable that collections be formed of these rhomboidal or prismatic bodies, for the purpose of inquiring into the causes of their production.

e. Cleavage is by no means confined to those rocks which are divided into beds and have been deposited through the agency of water. Rocks which would be otherwise massive, and which are referred to an igneous origin, are also divided by cleavage planes. In granite this is a very common circumstance, and portions of that rock often appear as if artificially arranged from this cause. The cleavage of granite is generally such, that the mass is divided into numerous short prisms

Fig. 102.

with a rectangular base.   These, when exposed to the
action of the atmosphere, or that of the sea on coasts,
frequently present the appearance of some huge ruin.
The blocks are generally, as in the annexed sketch
(Fig. 102), so piled upon each other as to form tall
prisms, composed of several others having an equal base.

   f. An observer should carefully direct his attention,
in the cleavage of protruded granite, to the influence
which, by giving a particular form to the mass, an ad-
joining surface of pre-existing rock has apparently exer-
cised upon the lines.   Let the annexed section (Fig.
103) represent the junction of protruded granite, *b*, with

Fig. 103.

<center>*a*   *b*</center>
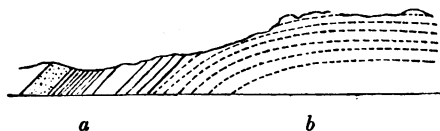
the pre-existing stratified rock *a*, which there is suffi-
cient evidence to show has been tilted up by the former:
then the observer should note how far the lowest sur-
face of the rock *a* has influenced the upper cleavage
lines of the granite *b*.   We have often seen, that in
such cases one set of cleavage lines takes the direction
of the dotted lines in *b*, causing the granite near its
junction with the stratified rocks to appear, at first
sight, like beds dipping in the same direction as the
latter.   Clearly to perceive that these are not true
beds,   the observer should search for perpendicular
planes of cleavage, cutting directly down through the
apparent beds.   He will often find two sets of perpen-
dicular planes crossing at right angles ; so that the mass

of granite is divided into numerous blocks, which sometimes rise in masses, forming those picturesque summits known by the name of Tors in the district of Dartmoor in Devonshire.

g. When granite and some other igneous rocks rise through a country in the shape of great bosses, it will be frequently observed that there is the same tendency of one set of cleavage lines to correspond with the external form of the boss ; and that these are again cut by other sets of cleavage lines, which cross each other nearly at right angles, and cut through the first set. Let the annexed diagram (Fig. 104) represent a sec-

Fig. 104.

tion of a boss of such igneous rock ; then the observer should see how far one set of cleavage lines corresponds with the external surface, as is, for the sake of illustration, supposed to be the case between the surface line *a b,* and the internal dotted lines.

h. At the junction of igneous rocks generally with those among which they have been protruded, an observer should carefully search for any traces of cleavage in the former. It most frequently happens that such cannot be found ; but as we have sometimes seen igneous rocks, such as certain porphyries and greenstones, split apparently by cleavage, into parallel planes, so as to give them a schistose structure, we would recommend more attention to this point than it has hitherto received.

i. In all cases of cleavage, whether of stratified or unstratified rocks, the observer should pay particular attention to the direction or strike of the cleavage lines, more especially to those which are perpendicular, or nearly so.   They have been observed in some countries to take given directions very constantly over considerable areas, even across several rocks.   These directions should be taken with reference to the true, not the magnetic North.

k. Certain igneous rocks are divided into a multitude of prisms, and are thence termed columnar.   Whether or not this kind of division should strictly be called cleavage, we shall not stop to inquire, but proceed, for the sake of convenience, to notice it here.   The Giants' Causeway and the Isle of Staffa are well known examples of the columnar structure of basalt in the British Islands.   In both these instances, the mass of basalt consists of beds, which appear to have been spread successively over each other in a melted state, particular circumstances having at times prevailed which rendered them columnar.   When the columnar structure is developed, the observer should note whether the columns be jointed, as in the annexed sketch (Fig. 105), or simply continuous from the top to the bottom of the mass,

Fig. 105.
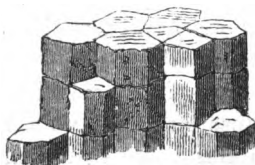
as in the annexed view (Fig. 106). When the columns are of great size, they should be measured. Some at

Fig. 106.
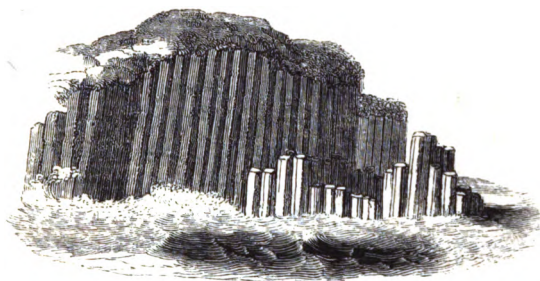
Fairhead, on the north-east coast of Ireland, were thus found to be 317 feet in height. The number of sides of which the prisms are composed should be noted, as also whether the prisms are very variable in that respect, or mostly hexagonal.

l. In all cases where a rock with this columnar structure is seen to repose upon another rock, the observer should see if the columns rise at right angles to the plane of the rock upon which they repose. Let, in the annexed sketch (Fig. 107), *a b* represent the section of

Fig. 107.
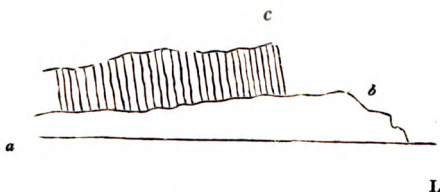
a plane of rock upon which a mass of columnar rock re-
poses; then it should be seen if the columns of *c* are, or
are not, at right angles to the line *a b*.   With regard
also to the columnar structure sometimes observable in
the igneous rocks forming dykes (see p. 30), it should
be observed whether or not the columns extend per-
pendicularly from the walls of the dyke to the central
parts.   Let *a* (Fig. 108) be a dyke of igneous rock in-

Fig. 108.
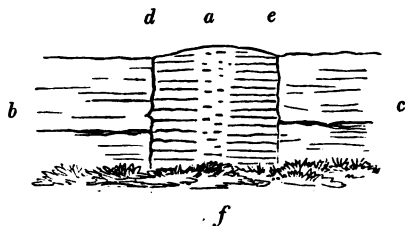
terposed between the once continuous beds *b c ;* then it
should be seen if the columns extend perpendicularly
from the walls or sides of the dyke *d* and *e*, as we have
here represented them ; and if so, whether there is a
certain amount of confusion in the central portion of
the dyke *a f*, as in the figure, or whether the columns
actually traverse from side to side.

   m. The igneous rocks in which the columnar struc-
ture is developed are very various, comprehending some
lava currents, basalts, trachyte, pitchstones, greenstones,
numerous porphyries, and others of the like kind.   The
observer therefore must not suppose that because a rock
is columnar it is necessarily basaltic, as is somewhat the
opinion of those unacquainted with geology.   This
structure does not even prove that the rock exhibiting

it is of igneous origin, since it has been observed that beds of aqueous production, such as sandstones, are occasionally columnar beneath, or adjoining to, masses of igneous rock; and it is inferred that this arises from the long-continued heat to which the aqueous rock has been subjected before the igneous matter finally cooled, since similar effects can be produced artificially.*

n. The columns are not always straight. They are sometimes curved, as in the annexed sketch (Fig. 109).

Fig. 109.
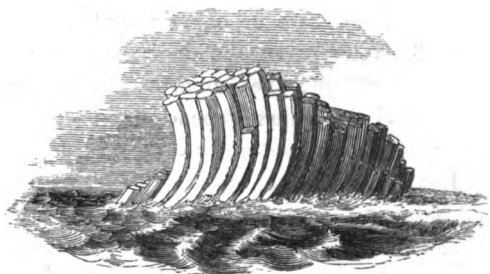
It would be very desirable in such cases to observe, if possible, what modifying circumstances have produced this deviation from the more common arrangement; whether it depends upon an irregularity of the surface on which the columnar rock rests, or on something in the latter itself.

XXII. *Fossiliferous rocks, or those which as a mass contain organic remains.*—Having previously (p. 8) shown that every bed comprised within this class does not necessarily contain organic remains, and

* See Quarterly Journal of Science, 1829; and Geological Manual, pp. 471, 472.

noticed (p. 13) the names which have been given to the various groups of which it is composed, in the order of their relative antiquity and superposition, we now proceed to the manner of observing them. The chief objects sought are their relative order of superposition, the manner in which they have been formed, and the nature of their respective organic contents.

a. Direct observations on the actual superposition of any series or groups of beds are necessarily those of the first importance, since whatever value is to be attributed to mineralogical structure or organic contents, as characteristic of contemporaneous deposits over areas of greater or less extent, the importance of these supposed characteristics must depend upon observations which show the actual continuity of the deposits themselves. Let the annexed woodcut (Fig. 110) repre-

Fig. 110.

sent a section in which three groups of beds can be traced continuously from *a b c* on the one side to *a′ b′ c′* on the other; it will be obvious that if they can be demonstrated to be three continuous and distinct masses of matter, they may differ entirely both in mineralogical structure and organic contents at *a b c* and *a′ b′ c′*, and yet be of contemporaneous origin respectively, geologically considered. Mineralogical structure and organic remains, be their value what it may, must be subordinate to actual superposition.

b. If rocks were bared of all vegetable and other co-
vering, so that an observer could actually walk upon a
series or group of beds from one part of a country to
another, or, extending the area, traverse several coun-
tries, he would constantly see beneath him any changes,
whether of mineralogical structure or of organic charac-
ter, which might take place in any series or group of
rocks that he might be tracing. As he cannot do this,
he must look to natural or artificial exposures of rocks
for such information on this head as he can obtain.
These he finds on sea-coasts, on the banks of rivers,
among mountains, in ravines of various kinds, in mines,
in roads and lanes, in lines of canals, &c. It will be
obvious that an observer must set out from some place
in which the series or group of beds he intends to trace
has a certain mineralogical structure, and, in the case of
the rocks under consideration, contains certain remains
of animals or vegetables, as the case may be. The
student of geology may here very properly inquire how he
is to know when he is on any particular series or group
of rocks, if a contemporaneous deposit may possess a dif-
ferent mineralogical structure at one place and at an-
other, and may even differ in its organic contents;
though respecting the latter character it is but fair to
state, that numerous geologists so confide in it that they
take it as a guide in preference to all others, even con-
sidering it as conclusive evidence. We would advise
the observer in Europe to adopt those various groups
into which, after considerable labour, geologists now
divide the fossiliferous deposits of this part of the world.
Many, no doubt, are very artificial; but they are ex-
tremely convenient, at all events, in the present state of

science. In other parts of the world, where as yet
geological researches have not been so extended, we
would strongly urge geological observers to examine
countries with reference to the structure of such coun-
tries respectively, and not employ those names alone
which have been given to particular groups in Europe.
It will be evident that given groups of the fossiliferous
rocks may eventually be traced through various modifi-
cations from Europe into Asia and Africa; but when
any such rocks are at once assumed, without intermediate
points of comparison, to be the same in distant places—
such, for instance, as India—with the minor divisions of
European deposits, we are evidently in danger of com-
mitting most serious errors.

c. Respecting a considerable part of Europe, parti-
cularly its western portions, an observer will find so
much valuable information in various geological maps,
treatises, memoirs, and local works, that there are not
many situations in which he could not obtain some infor-
mation as to the supposed general structure of any
locality he may be desirous of examining; and as far
as our geological experience extends, now nearly over
twenty years, he will find the more advanced geologists
ever ready to assist him in his labours. Still he should
proceed to examine the relative superposition of the
rocks in any district he may wish to explore, in order
to convince himself that the opinions advanced on such
subjects are correct; and he can do this even without
knowing to what particular groups the rocks before him
may be eventually referred. Instructions on this head
will obviously also apply to those countries where rocks,

from the want of sufficiently extended researches, have
not yet been arranged in groups.

d. Let us suppose that an observer has a range of

Fig. 111.

a   b   c   d   e   f
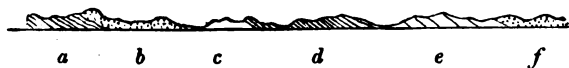
cliffs before him, such as is represented above (Fig. 111),
and that he commences his labours with the lowest
visible rock, *a;* he will note its mineralogical structure,
that is, he will see whether it be a marl, sandstone,
limestone, or the like. Let us suppose that *a* is a lime-
stone composed of numerous beds. The observer
should now search for organic remains in them, which,
for the sake of illustration, we will consider that he finds,
and that he carefully distinguishes the fossils obtained
from each bed by marks which prevent error in this
respect. Let us further suppose that *b* is a siliceous
sandstone, which we thus divide from the limestone *a*,
because all analogy would teach us that the causes pro-
ductive of a siliceous sandstone must differ from those
which formed a limestone. He will now search for or-
ganic remains in the siliceous sandstone *b;* and thus he
will proceed with the respective rocks *c, d, e, f,* which
we suppose to differ mineralogically from, and clearly
to rest upon, each other; the observer having satisfied
himself, by proper researches, that all chances of error
under this head have been carefully avoided.

By proceeding in this manner, he obtains a certain
series of deposits which he provisionally assumes to be

distinct. He may now either search for other deposits occurring above or beneath this series, or he may trace its continuity horizontally through the district. In the latter course, he necessarily sets out with a knowledge of the superposition of the rocks exhibited in the cliff section, and is therefore in a condition to appreciate any change which may take place, either in their mineralogical structure or organic contents, as he recedes from the situation where he first directly observed their relative superposition. If he has carefully attended to all the natural or artificial sources of information that present themselves, he will see whether any two rocks, which were fairly distinct in the cliff section first noticed, merge into a deposit that should be considered as one only,—or whether, on the other hand, another rock should gradually become developed between two others, so that it will be necessary to distinguish a deposit between some two of those noted in the first section, and of which no traces exist there.

For the sake of illustration, we have assumed that the cliff section (Fig. 111) was of the most simple kind, the rocks resting in a parallel manner; or, as it is termed, *conformably* upon each other. We cannot afford space for notices of the variable manner in which rocks may rest upon each other. However this may be, the principle on which to conduct the inquiry remains the same. The first object sought is direct evidence, if it can be procured, of the relative superposition of the various rocks observed.

e. It may be necessary to notice briefly that kind of superposition which is termed an *overlap*, since it is one which may lead to erroneous conclusions. Let the

annexed diagram (Fig. 112) represent the section of a
country several miles in length, and that an observer is
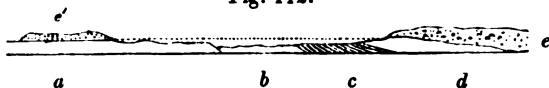
so placed as to have the left-hand portion under ex-
amination. He there sees that the rock e' reposes upon
a. This he notes in the manner directed, and due care
is paid to their mineralogical structure and organic con-
tents respectively. He might now conclude that in
the series of rocks generally e' succeeded a. Let us
now suppose that the observer is desirous of extending
his researches towards the right hand, and that he pro-
ceeds in that direction until he encounters the rock b;
upon examining which he becomes startled by finding
that it is not the same, either in mineral or organic
character, as the rock e', and yet that both succeed b
in the order of superposition upwards. He might be
tempted to believe that b was the continuation of e', not-
withstanding the differences above noticed. In this he
would evidently be wrong, as e' is an overlap, being the
continuation of e on the right hand, — a rock which
comes, in the order of succession, after d, which is it-
self separated from a by b and c. In such cases as
these, e and e' once formed continuous portions of the
same rock that has been thus separated by the action of
denuding surface-causes, which have not only destroyed
the continuity of e, e', but also cut somewhat into the
beds beneath. It will be obvious that any newer de-
posit may overlap or rest upon an older; and that

L 5

numerous intermediate deposits, which would complete
the series in any given part of the world, may be want-
ing, as it is termed, between them.

f. Groups of rock, though composed of beds that
differ mineralogically from each other, such as marls,
sandstones, conglomerates and limestones, which over-
lap other groups, should be duly noticed, more particu-
larly when the appearance of the inferior beds justifies
us in concluding that they have been subjected to the
action of a disturbing power before the superior rocks
were formed. Let *a a* in the annexed section (Fig. 113)

Fig. 113.
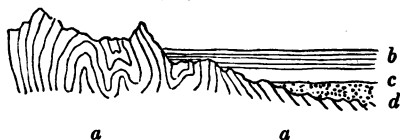
represent some given rock, such, for instance, as a mix-
ture of dark-coloured limestones and argillaceous slates,
partially covered by a red conglomerate, *d,* a light-
coloured limestone, *c,* and a gray marl, *b ;* then there
will be no difficulty in perceiving that *a a* was disturb-
ed and contorted before *b, c, d* were deposited ; and,
consequently, that *d* may not be the next rock to *a* in the
series, viewed generally, since, in those situations to
which the disturbing force did not extend, tranquil de-
posits may have been effected between the production
of *a* and *d* respectively. In the section before us (Fig.
113) the observer would have evidence that the group
of rocks *b, c, d* was quietly deposited upon the up-
turned and contorted strata *a a,* and that therefore they

do not form component parts of the same group, at least in this locality. By proceeding in this manner, without absolutely depending either on mineralogical structure or organic character, though these are highly necessary aids, various groups of beds may be established in extensive districts, which, as masses of matter, have been formed successively and independently of each other.

g. An observer should bear in mind that a particular portion of the earth's surface may have been so situated relatively to another, that traces of a series of deposits effected in one place can only be very differently, if at all, represented in another. It will be difficult to re-present this by a diagram in so small a space as this page; but perhaps the annexed sketch (Fig. 114) may to a certain extent assist the reader. Let the arc a b

Fig. 114.

represent a section of the sea-level over part of our planet, c d, the solid surface of the earth, which rises above the sea-level at e, constituting dry land, while it plunges beneath that level at d and forms the bottom of the sea: it will be clear that numerous marine de-posits may be effected upon d, while a comparatively small amount of lacustrine or fluviatile deposits may be thrown down on c. In fact, after a certain time the latter may be hardly appreciable, while the former con-tinue as abundant as ever. Compare, for example, the

amount of deposits which may now be forming on the surface of the British Islands with that which may be taking place in the seas around them. Let a geological change be effected in the part of the earth's solid surface represented above (Fig. 114), so that the dotted line *e f* represents its position relatively to the sea-level *a b*, which, for the sake of illustration, we have supposed to remain much the same;—*e* will now form the bottom of the sea, and *f* will constitute dry land ; *e* therefore will now be the surface on which marine deposits are effected, and *f* will receive the terrestrial. To render our illustration simple, we have been compelled to suppose these changes in the relative positions of sea and land to have been so effected that the point *h* always formed a coast. Such a condition of the point *h*, it may hardly be necessary to remark, would be in the highest degree improbable. We can do no more, in this confined space, than endeavour to illustrate the principle sketched above : there will be no difficulty on the part of the observer in imagining numerous modifications of it. Under such conditions, the probabilities would be, that the greatest differences would be observed at the greatest distances, *a* and *b*, while the least would be found at the intermediate point *h*.

h. We now proceed to note the mode of observing the mineralogical structure of the fossiliferous rocks, not because we consider this structure more important than their organic character,—that is, the general character of the organic remains found in them,—but because inorganic mineral matter constitutes their mass. Viewing this matter generally, and from its present condition, we infer that it has either been mechanically or chemi-

cally deposited ; that is, has either been pushed forward
by moving water, thrown down from moving or still
water in which it was mechanically suspended, or has
been chemically separated from sea or fresh water in
which it was, for the time, held in solution.

i. When an observer finds a *conglomerate,* that is, a
number of rounded pebbles cemented together by some
substance, such as a sandstone, limestone, clay, or the
like, his first object should be to ascertain the nature
of the pebbles. He will carefully see if they consist
of rocks known in the neighbourhood : older than the
conglomerate they must of necessity be, otherwise they
could not be included in it. He will then, if the peb-
bles be of different kinds, estimate the relative propor-
tions of each. He will now be in a condition to judge
of the relative distances they may have been moved
to their present situations, and also of the direction
whence they may have travelled.—We must here cau-
tion the observer against a circumstance which some-
times happens. A conglomerate may consist partly of
pebbles derived from a more ancient conglomerate, and
partly of rounded fragments of more simple rocks, such
as sandstones, limestones, and the like. In such cases
it would be right to learn the composition of the more
ancient conglomerate before the observer proceeds to
judge whence certain pebbles have been derived.—An-
other circumstance should also receive attention. It
occasionally happens that rounded fragments are dis-
covered in a conglomerate which cannot be traced to
any known rock, either in the neighbourhood or at con-
siderable distances. We have noticed this fact in con-
glomerates (of the red sandstone series) which were

mixed with trappean rocks, produced probably in a
manner not very different from the lavas of a modern
volcano. In such cases we may either consider that
these pebbles have been ejected from a volcanic crater,
as often happens at the present day, or form parts of
masses of trappean or other rocks concealed beneath the
conglomerate.

k. The term *breccia* is applied to the angular frag-
ments of rocks which are cemented together by lime-
stone, clay, sandstone, or the like. From this form of
the fragments we infer that they have not been exposed
to much friction, and, consequently, have not travelled
far. We necessarily expect to find little else than the
fragments of those rocks on which the breccia immedi-
ately rests. Let *a* (Fig. 115) represent the section of

Fig. 115.
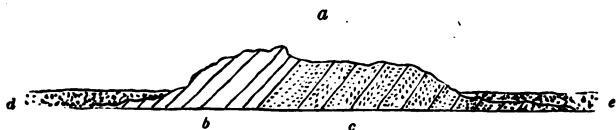
a ridge of pre-existing rocks, composed of a limestone,
b, and a siliceous sandstone, *c*, and *d* and *e* breccias
on either side: then, as a general fact, the observer
would find the breccia *d* composed of fragments of the
limestone *b*, while *e* was formed of fragments of the
sandstone *c*, and yet *d* and *e* may have been contempo-
raneously formed; the causes which produced fragments
of the respective rocks and their subsequent consolida-
tion into breccia having acted simultaneously on both
sides of the ridge *a*.

l. It sometimes happens that there is a mixture of

angular fragments of rocks and of rounded pebbles in the same bed. The observer should carefully note the nature both of the fragments and of the pebbles, distinguishing any difference between them, and their amount relatively to each other; remarking, in such cases, how far the mass may resemble an ancient shore, in which there was a mixture of angular fragments, semi-rounded and rounded pebbles, all of the same rock,—or whether the rounded pebbles have been derived from a distance, and the angular fragments from pre-existing rocks of the immediate vicinity. Alternations of conglomerates and breccias are occasionally found constituting one great mass of beds; as also a thick bed of conglomerate resting upon another of breccia, or the reverse. These facts and their attendant circumstances should be carefully noted.

m. The distinction between a fine-grained conglomerate and a coarse-grained sandstone is of necessity to a certain extent arbitrary, as they merely form intermediate and consecutive states of the comminution of matter by friction from large fragments to a fine powder. Perhaps, so long as the rounded grains show clearly that they have been derived from some known rock, the mass of which they are the principal component parts may be termed a conglomerate. When an observer discovers that a conglomerate bed gradually becomes finer grained, and finally passes into a sandstone, it is very desirable that he should note the conditions of the change. If the whole has been formed upon a pre-existing surface by a movement of water which pushed detritus over it, he may in many instances learn the direction whence the whole is derived, even

when the bed becomes a sandstone, by searching for
diagonal lines, such as those represented in the annexed
section (Fig. 116) in the bed *a*, which from analogy

Fig. 116.

we infer have been caused by the pushing process of
moving water previously noticed (p. 71).   By gently
clearing away portions of the sandstone, the planes of
which these diagonal lines are sections can often be
obtained, and their dip and strike can be ascertained
in the same manner as those of thick beds or strata
(p. 190).   Having done this, the observer obtains a
general idea of the direction whence the sand forming
the sandstone was derived, by considering it at right
angles to the strike of the diagonal laminæ, and oppo-
site to the direction of the dip; since such must have
been the direction whence the particles of sand were
pushed over the inclined plane towards the surface *b*
(Fig. 116).   We say a general idea, because we can
scarcely suppose, that the gradually advancing line
over which the particles of sand were pushed would be
straight: it would, probably, be curved or composed

Fig. 117.

of numerous minor protrusions, when seen from above,

in the manner represented in the annexed horizontal plan (Fig. 117), and therefore it would be necessary to obtain the general strike of the planes of laminæ in order to learn the direction of the pushing action of the moving water.

n. The observer will frequently find these minor lines of section in sandstones exceedingly various ; and as much may be learned from them, correct drawings of those exhibited in natural or artificial sections are very desirable.   Let us suppose that one of the following kind is thus obtained (Fig. 118); then, commencing

Fig. 118.
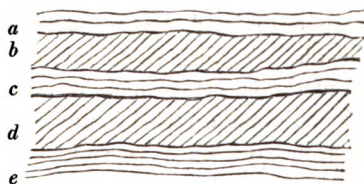
with the lowest part, we may infer that *e* was a bed of sand, the particles of which were thrown down from water in which they were mechanically suspended ; *d,* another bed formed by the pushing process ; *c*, a precipitate from mechanical suspension ; *b*, the result of the push-ing process along the bottom ; and *a*, a bed formed in the same manner as *c* and *e*.   If the planes of the la-minæ of *b* and *d* coincide generally, it may be further inferred that the direction whence the moving power acted was the same in both cases ; in other words, that the current, or moving body of water, which by friction pushed the sands onwards along the bottom, took the same direction in both cases.   The observer will some-

times find considerable confusion in the lines of laminæ,
with intermixtures of coarse and fine sand, and even of
conglomerates, which may induce him to conclude
that there has been much confusion in the directions
and velocities of the currents of water, which have either
pushed detrital matter onwards, or, from a diminished
rate of movement, lost the power of sustaining it in its
state of mechanical suspension.

o. As from all analogy we consider conglomerates
and breccias to have once been loose rounded pebbles
or fragments of rock, which have been subsequently
formed into a compact mass by the cementing substance
now found between them ; and, in like manner, that
sandstones were once incoherent sands, now consoli-
dated ; so do we infer that fossiliferous shales, fine-
grained slates, marls, and clays, were once mud, which,
according to its original composition, and the circum-
stances to which it has been subsequently exposed, has
assumed the forms we now see.   We should infer that
the finer the matter mechanically suspended in water, the
more extensive and uniform would be the deposit from
it, when circumstances permitted or caused its descent
to the bottom from a moving mass of water ; and hence
that, in a series of such mechanical rocks as those now
under consideration, the marls, clays, or slates, as the
case may be, would be more uniform throughout hori-
zontal distances than the sandstones, and these latter
more uniform and extensive than the conglomerates. An
observer should therefore carefully attend to this point,
and narrowly search for circumstances which may have
produced modifications of it.

p. It often happens that there are concretions and

spherical or spheroidal nodules in sandstones and clays which are considerably harder than the rocks that include them. Let the observer note whether they occur in lines parallel to the general stratification, as is the case with those represented at *a* in the annexed section (Fig. 119), or irregularly dispersed through the

Fig. 119.
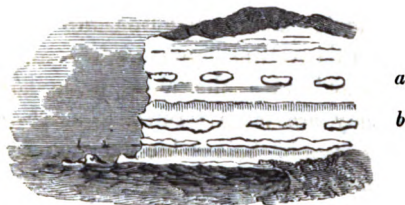
rock. Having obtained a nodule, let him examine if it be composed of concentric coats, or formed of laminæ parallel to the general stratification of the beds. He should also see if the matter of the nodules differs from that of the surrounding rock, noting whether or not there has been an aggregation of similar matter, such as carbonate of lime and the like, apparently separated from the mass of the rock after deposition. It often also happens that these indurated portions extend out in the shape of imperfect beds, as at *b ;* so that when the including marl, clay, or sandstone, as the case may be, is removed from them, they constitute a series of irregular flattened masses arranged in the same plane, which, when viewed from above, have the appearance of the annexed plan (Fig. 120), where the shaded portions represent the flattened masses, and the dotted parts the including rock, both seen from above. These

Fig. 120.
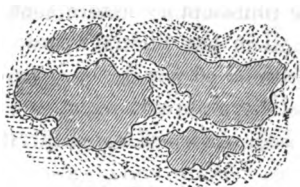
and similar facts should be noted, since they lead to
much curious theoretical inquiry.*

q. Intermixed with the above-noticed *mechanical
rocks*, as they are often termed from their supposed
origin, limestones of various kinds are more or less fre-
quent. Some may be also perhaps termed mechani-
cal, while the rest are inferred to have been formed
by some chemical change in the water in which the
carbonate of lime was held in solution, such as the loss
of the disseminated carbonic acid which previously ren-
dered it soluble, so that the matter of the limestone
was deposited. The observer will direct his attention
to the compactness and other characters of these lime-
stones, noting their connexion with the rocks associated
with them. Some siliceous sandstones so resemble cer-
tain limestones, that more care is necessary in distin-
guishing them than an inexperienced observer may at
first sight suspect. It hence is extremely desirable that
he should furnish himself with a small bottle of acid,
(muriatic is that most commonly employed,) for the
purpose of detecting the difference on the spot. Con-

* For further observations respecting the aggregation of similar
matter in the mechanical rocks, see Researches in Theoretical
Geology, p. 94—100.

venient bottles for containing the acid can readily be
procured at the philosophical instrument maker's.

r. We cannot, in our limited space, detail the nu-
merous modifications of mineral structure which can be
observed in the above-noticed rocks, nor of the associa-
tions of the mechanical and chemical deposits in the
fossiliferous series.   Some modifications are considered
characteristic, and are undoubtedly of considerable va-
lue when proper attention is paid to the relative areas
over which they occur.   Thus, the well-known rock
called chalk forms a particular deposit from the north
of France; through the British Islands, part of Ger-
many, Poland, and European into Asiatic Russia.
This form of carbonate of lime is not, however, con-
fined to this particular deposit, neither does the latter
always appear as chalk; so far from it, that deposits,
considered to be contemporaneously produced with the
white chalk above noticed, are formed of dark-colour-
ed marble limestones, and even siliceous sandstones.
Again, another group of rocks is, for convenience,
termed oolitic, because some of the component beds
in western Europe are formed of limestone, composed
of little rounded and often concretionary grains, which
resemble the roe of a fish.   This structure is not con-
fined to the group in question, but is found in others;
neither do rocks contemporaneously produced with it
necessarily show any traces of it.

s. For the various modifications of mineral structure
found among the fossiliferous rocks, we must refer to
treatises on geology : we can only here direct the atten-
tion of the observer to them generally, endeavouring to
show, that if we desire to arrive at their causes, due

regard must be paid to the mode in which the various
rocks, noticed above, occur relatively to each other, the
changes of structure which take place in horizontal
directions, and any other circumstances which may lead
us to the object desired.   Fearful of appearing to bias
the opinion of the reader upon points which may as yet
be considered unsettled, we abstain from pressing upon
his attention one series of facts more than another : we
must leave him to infer from his own observations whe-
ther the various fossiliferous rocks have been produced
by the same kind of agents which are now daily in force
on the surface of our planet, or whether greater intensi-
ties of similar or different agents may be considered
more or less necessary partially, or in any manner, to
explain the various phenomena observed.

    t. We now arrive at the subject of organic remains,
the relative importance of which must not be considered
with reference to the space here allotted to it.   From
being once utterly neglected, it has become one that
has excited the greatest interest.   It has risen into im-
portance as the supposed exclusive value of mineralogi-
cal structure sunk ; and as the latter, after receiving too
much attention, is now in some danger of not receiving
enough, the value of organic remains may perhaps,
after having been neglected, be now somewhat over-
rated.   Upon this subject, however, we must leave the
observer to deduce his own conclusions, and refer him
to nature for the best evidence he can procure upon it.
We should advise him, if opportunities offer, to study
the forms of the various genera of fossil shells, corals,
plants, and other organic remains, which are collected
in museums ; obtaining, as much as possible, the aid

of competent persons to direct his researches, in order
that his eye may become accustomed to such forms.

To acquire a knowledge of all the small differences
which are supposed to characterise different species, re-
quires very great application and comparison : in fact,
it is a study, and a laborious study, of itself. The
geologist who has devoted many years to his science
may indeed gradually accumulate a great amount of
knowledge on this head ; but this being a work of time,
those who have not laboured long at observation must
content themselves with leaving the determination of
species to experienced geologists, who have well studied
this subject, or to those naturalists who have occupied
themselves with zoological and botanical geology, either
by itself, or as an extension of their more peculiar in-
quiries. We more particularly caution young observers
on this head, because it is considered that certain spe-
cies, more particularly of shells, characterise contempo-
raneous fossiliferous rocks for considerable distances,—
and that hence, there being a general disposition in
those who commence the study of a science to consider
the received opinions of the day as all equally well
founded, species, though something like when hastily
viewed, may be stated to occur in situations where they
are not found. We do not mean to enter upon the
delicate question of the necessary distinctions between
species and varieties ; we merely call attention, for the
purpose of avoiding error, to the importance of leaving
such subjects to those who have devoted their time
to them.

u. One of the first objects to which the observer
should direct his attention is the mode in which organic

remains occur in rocks. If this be coupled with the
mineral structure of the latter, he may obtain an insight
into the manner in which the remains of animals and
plants, now found fossil, have been entombed. In the
first place, he should carefully note whether they pre-
sent any marks of having been rolled or transported
from greater or less distances,—or whether the plants,
shells, corals, &c. preserve their forms so uninjured that
it may be fairly inferred they have been enveloped by
the matter of the rock in the relative situations where
they now occur. Let us suppose that *a*, *b*, and *c* in
the annexed section (Fig. 121) are a sandstone, a lime-

Fig. 121.
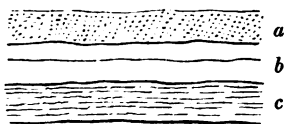
stone, and a marl respectively, and that each is fossil-
iferous, containing fossil shells; and further, that the
latter are fractured and worn in the sandstone, beau-
tifully preserved in the limestone, and compressed or
crushed individually in the marl, though otherwise per-
fect in the latter. The observer may fairly infer that
the organic remains in the sandstone are not found in
the situation where the molluscs or conchifers, of which
they are the exuviæ, once lived, while such may rea-
dily be the case with those in the limestone and marl.
Another condition of the fossil shells is, we have sup-
posed, to be compressed in the marl while they are un-
injured in the limestone. This will readily be under-

stood to be the result of pressure exerted upon the marl · by the weight of any rocks that may have been formed above it. From all analogy, we consider that as the limestone accumulated, it encased the shells in hard, solid matter, so that the whole formed one com-pact mass, and therefore the shells would not be com-pressed by the weight of any superincumbent rock. This, however, would not be the case with the shells in the marl, which we suppose, from analogy, to have been in the state of mud when the former were included in it, and hence, that when pressure was exerted upon the mud, the shells became crushed in their places.

It must not be inferred, from the illustration above given, that organic remains are necessarily worn and otherwise injured among sandstones, and well preserved in other rocks ; for fossils are frequently perfect in the former. We are merely desirous of calling attention to the condition in which organic remains are discovered, and of showing that such condition should be consider-ed with reference to the mineral structure of the rocks in which they are found.

v. It is always desirable to note those facts which may enable us to judge whether the animal and vege-table exuviæ discovered have been quietly entombed, or have been brought to rest by deposition from a rush of waters, in which animals or plants were tumultu-ously borne onwards with gravel, sand, or mud. As we cannot conceive that limestones have been produced otherwise than in a tranquil manner,—at least those which do not appear to have been aggregations of car-bonate of lime from mud after deposition,—the observer is in no great danger of error if he considers the beds of

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limestones to have been respectively produced on a
bottom beneath water, and that any changes in the
organic contents of the various beds arose from changes
in the kinds of animals which existed on the bottom,
and that these may have been occasionally mixed with
animal and vegetable exuviæ drifted from a distance.
When therefore he sees the section of a limestone bed
with organic remains in it, he has before him a portion
of the bottom of a former lake or sea, except in such
cases where it may be inferred that the limestone bed
has been produced by the gradual deposition of carbon-
ate of lime, in successive incrustations, upon grass and
other substances, from the evaporation of the water which
contained it in solution, as is often seen upon land.

When an observer finds that organic remains are
arranged in planes parallel to the general stratification
of the including rock, as in the annexed sketch (Fig.
122), where the broken lines parallel to those of the

Fig. 122.
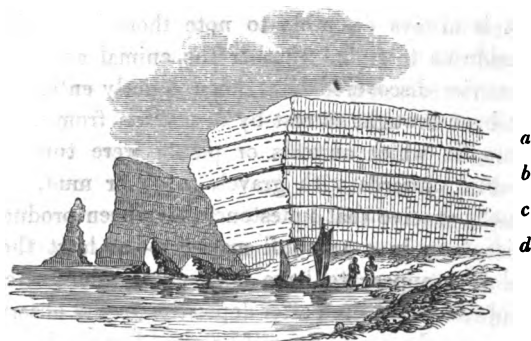
beds represent lines of marine organic remains, then the evidence would lead him to infer that he has before him a section of several distinct and successive bottoms of the sea, that the organic exuviæ in the beds have also been accumulated on these bottoms in succession, and that they have been tranquilly covered up, one accumulation after the other, in the order of their relative superposition. For the sake of further illustration, let us suppose that the cliff is composed of a calcareo-siliceous sandstone, *a ;* a coarser grained siliceous sandstone, *b ;* a marl or clay, *c ;* and an argillo-siliceous sandstone, *d.* Then he would be enabled to infer that, as far as the evidence of the locality went, the bottom of the sea was at first a kind of silt; afterwards, mud; thirdly, coarse sand; and finally, a sand among which carbonate of lime was much disseminated. These would be the great changes of the bottom of the sea in which the whole mass before him was formed: the number of minor changes would be shown, if not entirely, at least to a great extent, by the number of the respective lines of organic remains visible in each bed.

It may be here noted, that in some rocks, such as marls and the like, where there seems to have been so constant an accumulation of fine detrital matter that the evidence of the successive bottoms of a sea or lake is exceedingly obscure, much assistance may sometimes be obtained by searching for lines of those singular fæcal remains, termed coprolites, for the knowledge of which we are indebted to the labours of Professor Buckland. It may readily happen that, in a bottom of mud, lines of organic remains would with difficulty be formed, some creatures burrowing in it to various depths, and the

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hard remains of molluscs, fish, saurians, and the like, tending to sink also to variable depths, according to their relative specific gravities. The fæcal remains of fish or aquatic saurians may have been showered in great abundance upon such bottoms, covering them with a sheet of coprolitic matter, of which part indeed may, from greater specific gravity, have descended lower than the rest, but of which the whole, taken as a mass, would be spread over areas that would depend upon the amount of supply from above. An observer may have proof that such a state of things was not improbable, by searching for sections of the accumulations in question; though it must not be inferred that these fossils are not found singly, for such is a very common fact.

w. When an observer discovers organic remains thrown together in a confused manner, without parallelism to the stratification of the including beds, he can scarcely consider that they are the remains of animals or plants which lived upon the bottom of the sea or lake, as the case may have been, and were tranquilly covered up,—or that they were lightly drifted to, or descended gently down upon, a pre-existing bottom on that spot. He should in such cases endeavour to learn the point whence the mixture of organic and inorganic substances has been derived, by noting the mineralogical structure of the rock in the manner previously recommended.

x. By comparing the forms of the various organic remains hitherto discovered with the animals and plants which at present exist, it has been inferred that they are the exuviæ of animals and vegetables which were, as now, terrestrial, fluviatile, lacustrine, or marine. With

regard to minor points of detail,—such as whether a particular species should, or should not, be considered marine or otherwise,—questions may occasionally be raised ; but there seems no reason, from any existing evidence, to doubt the correctness of the inference generally. We must refer to treatises on geology for those views which have been hence formed respecting the conditions of different portions of the earth's surface at various geological epochs. Terrestrial animals and plants, when mixed with aquatic, may evidently have been so in two ways : they may either have been borne onwards together by the same mass of moving water, and have been deposited from it, as the latter, from sufficiently diminished velocity, lost its transporting power ; or the terrestrial animals and vegetables may have been drifted, either violently or quietly, from dry land into water, beneath which both they and the aquatic organic remains were alike entombed in any deposit which might be subsequently formed. Having previously (p. 108) noticed the manner in which organic remains are entombed in deposits now forming, we merely now recall the attention of the observer to that subject, leaving him to judge how far the agents now in force will afford an adequate explanation of the various phenomena he may notice, and which are connected with this subject.

y. When an observer discovers a fossil shell, let him notice its position relatively to the stratification of the bed in which it occurs ; for we may infer that the plane of the bed was often nearly that of the plane of the horizon when the bed was formed. If it be an univalve, there may be some difficulty in inferring that its animal was

either dead or alive when the shell became fixed in its present position : if, however, it be a bivalve, it is by no means probable that its animal was alive if the two valves were open and turned either up or down, the valves extending horizontally as regards the plane of the including bed. If the shell be of a chambered kind, an ammonite for instance, and of which the nau-tilus affords a familiar example, he should note whether it rests upon its side or occurs in other positions. With respect to fossil shells, it may be here noticed that some kind of evidence may be obtained as to whether the animal was in the shell, no matter whether dead or alive, when enveloped by the matter of the including rock, by paying attention to the extent to which the latter has penetrated. Let the annexed sketch (Fig. 123) represent a section of an ammonite in a portion of

Fig. 123.
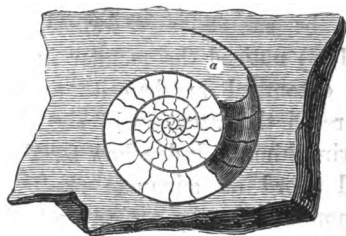
rock, the first external chamber of the ammonite, *a*, being only partially filled with the matter of the rock, (let it be an argillaceous limestone, such as part of the deposit named lias,) so that there is a portion towards the interior of the shell which either remains a cavity, or is filled with crystallized carbonate of lime, or other

substances, which have percolated through the rock in a
state of aqueous solution. In such a case, we may in-
fer that there was an obstacle in the first chamber of
the shell, when enveloped by the matter of the rock,
which prevented the latter from filling the interior part
of the cavity; and probably an observer would not err
greatly if he further inferred that this obstacle was the
fleshy body of the animal. He therefore might con-
clude that the ammonite in question was either enve-
loped by the matter of the rock while its animal was
living, or before it had time to suffer decomposition.

If echinites (commonly termed sea-eggs or urchins)
be the fossils found, the observer should remark if they
occur with their mouths downwards, as they would do
when at rest in a live state; and if they be of those
kinds which are armed with large spines, it should be
noted whether these are attached to the body of the
echinite; for if so, then it would seem to show that the
creature had been enveloped by the rock either alive, or
before decomposition took place sufficiently to cause a
separation of these large spines from the rest of the
body. Much information may thus be obtained re-
specting the condition of encrinites, insects, fish, rep-
tiles, and mammifers, prior to their envelopement by
the matter of a rock, by noting whether their harder
parts are relatively situated as they would be if still
held together by the fleshy or softer portions. If, for
example, an observer find a fossil saurian, as they have
been found, with all their bones in their respective
places, and in as good order as if in a prepared skeleton
of a recent creature, it is fair to infer that it either was
alive when first included in the matter of the rock, or

was so quickly enveloped by it that neither predacious
creatures had displaced the bones, nor decomposition
had caused them to fall into disorder. The perfect man-
ner in which some organic remains are preserved is most
remarkable ; the minute scales covering the skin have
been detected so completely in place in some speci-
mens of those fossil saurians named ichthyosaurus, that
they have the appearance of the skin itself.   The con-
tents of the intestines of fish and saurians have been
noticed not only in the relative situation they occupied
in the body, but also showing the form of the intestine
in which they occurred previous to death.   M. Agassiz
states that the capsule of the bulb of the eye is pre-
served in many fossil fish.

   While organic remains are thus sometimes as beauti-
fully perfect as if prepared for the purposes of instruc-
tion by the comparative anatomist, others are widely
scattered about, showing that they have either suffered
decomposition, and that their harder parts have been
thus separated from each other by moving water, or
that they have been scattered by predacious creatures.
Sometimes the bones of terrestrial mammifers are cover-
ed by fossil oysters, or the remains of other creatures
of like habits : this would inform the observer, that
the bones once lay without any fleshy covering upon
the bottom of a sea or estuary, and that the oysters
there attached themselves to them.

   It would be out of place further to notice the infer-
ences that may be deduced from the mode in which
organic remains occur in rocks ; the foregoing remarks
will be sufficient to show the importance of correctly
observing it.   It may nevertheless be stated, that while

some fossil plants show they have been drifted, some-times quietly, at others tumultuously, to their present positions, others pierce through several beds, or rise upwards in such a manner as to render it extremely probable that they were tranquilly enveloped in place by the matter of the rocks which now enclose them.

z. We should here offer some suggestions respecting the manner of obtaining specimens both of rocks and of organic remains. To obtain a knowledge of the true structure of a rock, unaltered by the action of the at-mosphere upon it, specimens should be obtained from situations where no decomposition from this cause has been produced. In some rocks these situations are near the exposed surface; while in others it is only at some distance beneath such surface, and by means of quarries, or other artificial excavations, that they can be attained. The observer, bearing this in mind, will therefore endeavour to procure specimens illustrative of the true character of rocks in those localities where he will best attain the object sought. It is also desirable to obtain specimens which may illustrate the amount of decomposition of certain rocks from atmospheric causes : these will necessarily be found near or on the surface. The specimens should advantageously display the struc-ture of the rock, and their size will depend upon the facilities which the observer may possess of transport-ing them. In all cases they should be sufficiently large to afford the information required from them. When obtained, the specimens should be carefully wrapped in paper, the locality having been written on a strip of paper and enclosed with the specimen; or a par-ticular mark may be made on the specimen, or enclosed

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strip of paper, which shall correspond with a similar
mark in the observer's field-book, in which remarks
generally, accompanied when practicable by sections,
should be carefully entered.

.When an observer has an organic remain before him
in a rock, he has the power, either, by carefully extract-
ing it, of rendering it subservient to the interests of
science, or, by haste and bad management, of render-
ing it entirely useless.   He therefore becomes either a
friend to, or at best a very lukewarm cultivator of,
science, according to the care he is disposed to take.
He may, indeed, not be successful in his attempts ; but
he should at all events use the best means in his power
to render himself so.   When the structure of a fossil is
extremely delicate, it is not desirable to endeavour to
extract it from the rock on the spot : on the contrary,
the observer should then strive to detach so much of
the rock, no matter whether the portion be great or
small, as shall, to the best of his judgment, envelope
the organic remain in a protecting case of stone.   And
if it should have unfortunately happened that a portion
of the fossil still remains behind in the rock, he should
labour to procure that portion also, and so on until the
whole of the organic remain in question be obtained.
In all cases, he had better not attempt to clean any fos-
sil, however apparently easy this may be, on the spot
where it is obtained.   The casing of the matrix or en-
veloping stone is valuable for the purpose of transport ;
and hence organic remains are generally in better con-
dition according to the little that is done to them prior
to their final deposit in cabinets and museums.

It sometimes happens that a fossil is so brittle, that

the vibrations produced by blows given to the matrix
enclosing it cause it to splinter up, notwithstanding
great care. If these splinters be sufficiently large, they
may be marked and re-adjusted ; but we should advise
the observer, when he sees a fossil beginning to splin-
ter, to take some stiff clay, if such can be procured, and
press it down upon the bone or other fossil he may
have before him. We have often found this plan to
succeed. It no doubt would be better to employ wax
or similar materials. This may advantageously be done
with small specimens, and a small piece of wax may be
carried about for this purpose ; but for large fossils
other means must necessarily be used. Upon objects of
great rarity and importance, or which rest exposed in a
very friable rock, which can be scarcely touched without
breaking, it may even be desirable to go to the ex-
pense of preparing plaster of Paris on the spot, and
cover the fossil—such, for instance, as the skeleton of a
fish or saurian—with a thick coating of it. By this pro-
cess the exposed part of the skeleton becomes set in a
block of plaster of Paris ; so that by working carefully
beneath it and the fossil in the friable rock, the skele-
ton is eventually on a surface of plaster of Paris, from
which it may afterwards be freed, or in which it may be
allowed to remain, as may be desired.

When the scattered yet well-preserved bones of ani-
mals are the fossils found, it often happens that by dili-
gent search a large portion of the entire skeleton may
be eventually obtained : so that when an observer dis-
covers a detached and well-preserved bone, he should
not too hastily conclude that no other parts of the same
skeleton occur near it ; he should, on the contrary,

narrowly search around for other portions of it. Again, the only indication of that which has often turned out to be a most beautiful skeleton, has been a small piece of bone rising through the rock. In such cases it no doubt requires a general knowledge of the structure of the remains entombed to obtain them in a tolerably perfect condition, and a more minute acquaintance with their osteology properly to develope their various parts. It cannot, therefore, be supposed that an unpractised observer will be as successful as those who are experienced. But, from what has been above stated, the former may learn that the accidental discovery of small portions of bone may sometimes lead to that of entire skeletons, provided sufficient care be employed. In many schistose or slaty rocks, organic remains, such as fish and plants, occur in great abundance among the laminæ, pressed down to so thin a substance as not readily to be seen in a cross fracture of the stone. When therefore an observer suspects that such organic remains are included in a schistose rock, he should endeavour to strike the detached portions of it, so as to lay open the stone in the direction of the laminæ. In this way multitudes of fossil plants may be obtained, of which there were few traces in the cross fracture of the rock.

With regard to the packing and transport of organic remains much care should be taken, the more delicate and small being wrapped in cotton wool, and put into small boxes ; nests, as they are termed, of which can readily be procured. The less delicate may be carefully folded in paper when not too large. The same precautions should be employed in correctly noting the localities as above

noticed (p. 249). An observer will find an angler's basket far more convenient than the sack or bag often employed for the purpose of carrying what are commonly termed hand specimens. When specimens are large and liable to be broken by any sudden jerk, such as skeletons of saurians in slabs of rock often are, we should particularly recommend the observer not to send them by conveyances without springs, if it can be avoided, and to adopt water-carriage whenever practicable.

XXIII. *Non-fossiliferous rocks, or those in which organic remains have not hitherto been detected.*—The general character of these rocks having been previously noticed (p. 9), we here proceed to offer some suggestions as to the manner of observing them. The objects sought in this case are their mineral structure and relative order of superposition.

a. For the names which have been assigned to the various mineral compounds of this class, we must refer, as before, to geological treatises. It having been supposed that beds, apparently of a mechanical origin, are sometimes intermingled with the crystalline rocks of the non-fossiliferous series, which we here strictly limit to those which occur beneath the grauwacke group of the fossiliferous class, the observer should endeavour to see how far this is true in districts which are unequivocally composed of such rocks as decidedly occur beneath the grauwacke. We say, in rocks decidedly beneath the grauwacke, because in districts of *altered rocks*, to be noticed in the sequel, and which very closely resemble those of the non-fossiliferous class, properly so called, such intermixtures are not unfrequent, owing to the unequal action of the altering cause.

b. The changes which take place in the mineralogical structure of the non-fossiliferous rocks in the direction of their strike are often highly interesting. Let us suppose that the observer is in a district composed of the rocks under consideration, and that the annexed wood-cut (Fig. 124) is a map of it. Let us further suppose

Fig. 124.
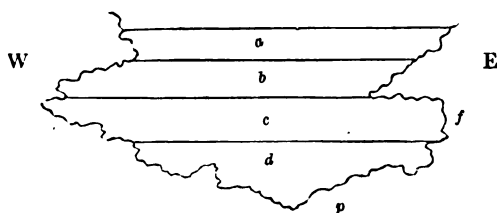
the strike of the beds *a, b, c, d,* to be east and west, and the dip to the south at a high angle. We will now imagine that the observer carefully examines the western coast, and that he finds the beds *a* are hornblende rocks composed of little else than hornblende and felspar divided into numerous beds; the beds *b,* mica slate, composed of mica and quartz; *c,* gneiss, formed of quartz, felspar, and mica; and *d,* mica slate, the same as at *b.* Having examined this part of the coast, let us suppose that he now passes round the point *p* to the eastern coast, and finds, as he expected from the strike of the beds, that the mica slate continues to *f,* where he anticipates that the gneiss of the western coast will make its appearance. Let us imagine, instead of this happening, that mica slate still continues to constitute the coast to the northward. He might at first consider

that, from the effects of faults between the two coasts, the rocks on the eastern side had been *heaved*, as it is termed, to the northward. If, however, he continues to find nothing but mica slate until he arrives at the point where, if the strike of the beds had been constant, and no dislocations had been produced by faults, the mica slate *b* should occur, and he discovers this mica slate including, as we will suppose for the sake of illustration, a multitude of garnets, the observer is prepared to consider that there had been a modification in the mass of the non-fossiliferous rocks of the district between the two coasts; and if he find that, in the line of the hornblende rocks of the western coast, there is a schistose rock, composed, we will suppose, of mica, hornblende, and felspar, he will be somewhat confirmed in this opinion.

c. Under the above circumstances, the observer should traverse the country intervening between the two coasts, which may either be a few or many miles apart, and fairly trace, by the various natural or artificial sections which may offer themselves, the different masses *a*, *b*, *c*, and *d*, from the one coast to the other, noting the gradual mineralogical changes—for they are generally gradual—which may take place in the range of their strike. It must not, however, be inferred that because a change of mineralogical structure may take place in one or more particular masses of beds, such as *a, b, c, d*, noticed above, that such changes should be found in all the associated beds of the like series; for it not unfrequently happens that some beds are very constant in this respect, while others are changeable. It is precisely by noting these various differences with accuracy and in detail,

that an observer may ultimately enable either himself or others to arrive at their causes.

d. It will be obvious that specimens, taken to illustrate any of the above-noticed or similar changes of mineralogical structure, if selected with judgment, are important. According to calculation, the differences in chemical composition, whence much diversity of mineral appearance may arise, are often small.* As, however, calculation merely gives us an approximation to the truth, and as this approximation must depend upon the supposition that the crystalline minerals, forming these rocks, are precisely of the same chemical composition as those the analysis of which has generally been made from very perfect specimens, it is highly desirable that specimens of the rocks themselves be analysed by competent persons. An able chemist would greatly advance this important branch of geological inquiry, if he were to select a district unequivocally composed of the rocks under consideration, note the various mineralogical changes which may occur, and carefully analyse such specimens as he may consider illustrative, not only of the changes of mineral structure, but also of those rocks to which particular names have been assigned, such as gneiss, mica slate, &c.

e. The relations of the non-fossiliferous rocks with granite should be carefully studied ; due care being taken not to confound the continuation of any intruded portion of the latter with a bed, or at all events a tabular mass. These tabular masses included among mica slate, gneiss with a schistose structure, and

* See Geological Manual, *Art.* Non-fossiliferous Rocks, 3rd Ed.

the like, are commonly termed gneiss when only a few feet in thickness. There are, however, theoretical con- siderations connected with them, that it would be out of place to notice here, which require that their connexion with any associated rocks should be correctly noted; and it should be particularly remarked whether, as in the annexed section (Fig. 125), the beds or tabular masses

Fig. 125.

c   b
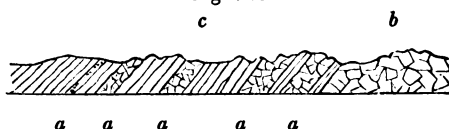
a   a   a   a   a

of the granitic rock *a, a, a, a, a*, increase in thickness and frequency as the mass of non-fossiliferous rocks *c* approaches another mass of granite, *b ;* due care being taken to see that the granite is not intruded.

f. Although it is generally considered, and appa- rently with good reason, that there is no definite order of superposition among the rocks of the class under consideration, that of any particular district on which an observer may be engaged should be carefully noted; and it is particularly desirable that the mode in which crystalline marble, or any other modification of carbon- ate of lime, occurs among the other beds, should receive attention. Care should be taken to ascertain whether such crystalline marble, or other carbonate of lime, forms a mass included among the mica slate, gneiss, and the like, or passes off into any other rock by a gradual dis- appearance of the carbonate of lime.

g. Due attention should be paid, in a district of the non-fossiliferous rocks, to ascertain whether all the beds,

or apparent beds, are conformable to each other, having generally the same strike or dip, or whether any portion rests unconformably upon another; proper care being taken, particularly in the latter case, to guard against erroneous conclusions from the occurrence of faults.

h. As the mode in which the rocks of the lowest part of the fossiliferous class may occur, relatively to those under consideration, involves questions of considerable theoretical importance, the observer should carefully direct his attention to those situations where the rocks of the two classes are in juxtaposition. He should note whether or not they pass gradually into each other; and if they do, then see if this be accomplished by alternations of the respective beds of each, or by the lowest beds of the fossiliferous series becoming gradually more crystalline.

XXIV. *Igneous rocks, or those which have once been in a state of fusion.*—The general character of these rocks has been previously noticed (p. 28), we therefore here confine ourselves to the manner of observing them.

a. In several parts of the world where volcanos are not now in activity, — such, for instance, as central France, and on the banks of the Rhine,—the observer will find conical heaps of cinders and ashes, and lines of rock, sometimes scoriaceous at top, diverging either from these heaps of cinders and ashes, or from less marked situations : in fact, he will see before him a state of things which more or less approaches that which he readily conceives to be one which Vesuvius, Etna, or any other active volcano, would present if their activity were to cease and the country were covered with vege-

tation. To such places the term *extinct volcanos* has been applied, though probably a similar propulsion of cinders and ashes, accompanied by the ejection of melted rock, which subsequently flowed in streams, either on dry land or beneath a moderate depth of water, took place through a long series of antecedent geological epochs.

b. The observations previously suggested (p. 127) for volcanos now active will in a great measure apply also to those which have been thus, for greater convenience, termed extinct. It will be obvious that the craters, cones of ashes and cinders, and lines of melted rock, which have either been long exposed to the degrading effects of atmospheric causes, or to the action of masses of moving water, would lose more of their original characters than those which have been a shorter time exposed to the destructive power of similar agents, all other things being equal. Hence the more an extinct resembled an active volcano in a state of repose, as it is termed, the more relatively modern might we be inclined to consider it. This, however, is a conclusion which should be drawn with reference to the supposed equal action of like causes upon like products, during equal intervals of time. It therefore becomes necessary that an observer should carefully note how far any extinct volcano, under examination, bears evidence of having been always exposed to the atmosphere. If an extinct volcano has, from any geological changes in the level of land and water, either been formed beneath moderate depths of the latter, and subsequently elevated into the atmosphere, or having been in activity in the latter, has at any time been exposed to the action

of tides, currents, or breakers, its relative antiquity
could not be well inferred from its appearance. Let us
take, by way of illustration, the case of the volcanic
island of Sciacca, thrown up in 1831 between Pantel-
laria and Sicily. The breakers, as is well known, have
washed away the accumulation of ashes, cinders, and
stones which once rose above the level of the sea, and,
no doubt, have acted beneath as far as their moving
force can be felt : in fact, the crater has been oblite-
rated and the volcanic accumulation rounded off.

Let us suppose that this volcanic vent continues
quiet, and that, from future geological changes on the
earth's surface, the volcanic mass is raised above the sea.
If the rise were gradual, it would still further suffer de-
gradation, and little would remain besides lava, now in the
pipe of the vent, and any streams of the same substance
which might have been thrown out beneath. We certain-
ly do not know that there is lava in the pipe, or streams
of the same substance thrown out beneath the level of the
sea ; but, for the sake of the argument, we may readily as-
sume this as an hypothesis. There will be no difficulty
in considering that this elevation might be accomplished
within a portion of time insufficient to cause any great
change in the present condition of some of the extinct
volcanos of Auvergne. It will be clear that if an obli-
terated crater be always taken as conclusive evidence of
the greater antiquity of one volcano than of another, of
which the crater was somewhat perfect, there might
come a time when it would be assumed, that the relative
antiquity of the volcanic accumulation in question was
greater than that of several extinct volcanos in Au-
vergne.

c. It being considered that igneous rocks have been
ejected from the interior of the earth both in the man-
ner of modern volcanos and in large masses, the ob-
server should direct his attention to those points which
illustrate this subject.   The name *trappean* has been
assigned to various rocks, such as greenstone and the
like ; and the term is exceedingly convenient, provided
it be not assumed that such rocks have always been
thrown up in mass, and in a manner different from
that in which melted rock is now ejected from a vol-
cano, or compelled to enter into and fill up the cracks
produced in and around it.   We have entered more at
length than we should otherwise have done upon the
changes which might be produced on the former island
of Sciacca, if it were so washed, either gradually or sud-
denly, by the sea that its harder parts only remained,
because we consider we have seen situations in which
trappean rocks have been so covered over by, or inter-
mingled with, deposits of aqueous origin, that the wash-
ing away of the softer parts of a volcano, and the sub-
sequent envelopement of the harder by aqueous de-
posits, would best explain the undisturbed condition
and apparently unchanged character of the latter.   Let
us suppose that an observer meets with an isolated
portion of some igneous rock, of a somewhat oval form
and of very moderate size, rising in the midst of a dis-
trict of sandstone and conglomerate ; and let us further
suppose that, searching for evidence of disturbance
among the sandstone or conglomerate beds, he finds
none, and that no change moreover can be seen at the
junction of the sandstone or conglomerate and the trap-
pean rock, which latter he discovers by natural or arti-

Fig. 126.
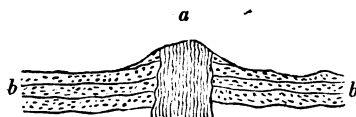
ficial sections, such as that above (Fig. 126), to rise
like a column through the beds of aqueous origin, *b*, *b*.
He should now carefully examine the contents of the
conglomerate beds; and if he finds fragments of the
igneous rock included in them, he may fairly conclude
that the trappean mass stood isolated in water, and was
gradually enclosed by beds of sandstone and conglome-
rate, some of the materials of which were at least de-
rived from its partial destruction.   The trappean rock,
in such a case, would clearly be more ancient than the
rocks surrounding it.

   d. We have endeavoured, in the foregoing illustra-
tion, to illustrate a somewhat complicated subject in its
simplest form : it is, however, a form less frequent than
the more complex.   Let the observer now imagine that
the annexed sketch (Fig. 127) is a section of a vol-
cano, in which the vertical shaded part represents a

Fig. 127.
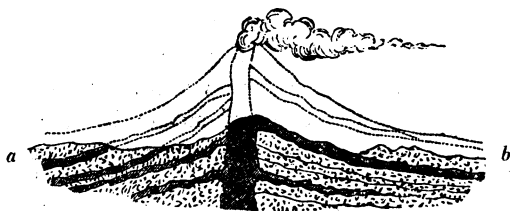
column of lava rising in the pipe or vent, and the sloping and horizontal shaded portions lava-currents which have, at various times, proceeded from the main pipe, so that when the lava in the latter became finally consolidated they would in some measure be joined to it. Let the dotted and unshaded parts represent beds of cinders, ashes, and stones, which are mingled with the lava-currents in a kind of irregular stratification. Let us now suppose that degrading surface-causes so act upon this mass of consolidated melted rock, and beds of ashes, cinders, and stones, that the line *a b* becomes the surface of the land, and we have a kind of trappean hill rising among beds of conglomerates, sand-stones, and the like; some of the lava-currents, when viewed on the surface, appearing like beds of trappean rock interstratified among the conglomerate and sand-stones. These effects will be greatly modified if the volcano has been sub-aqueous, and the modifications will be greater according to its depth beneath the surface of the water. Such effects would not be confined to one geological epoch, but would be common to all in which the various products could be arranged by volcanic action in the manner above noticed.*

* We have here neglected the fact, that the lava-currents would be braced together by dykes of lava, rising through cracks in the body of the volcano, and that thus the lava-skeleton, if we may use the expression, of a volcano, if all beds of ashes, cinders, and ejected stones were removed, would consist of a main trunk, from which numerous radiating lines descended in an inclined manner, so that the general appearance would be conical, and these radiating lines would be bound firmly together by numerous tabular plates, for the most part highly inclined, connected with the main trunk. These, no doubt, are subjects which should be attended

When an observer considers that any trappean rocks
he may have before him may have been ejected in the
manner of lava-currents, or be the remains of the conso-
lidated contents of the pipe of a volcano, he should first
see if they be in any way associated with conglome-
rates or breccias ; and if they are, he should carefully
search for fragments of the trappean rocks in them.
Should he find evidence that the conglomerates or
breccias are of more modern production than some of
the trappean rocks, it remains to be seen whether they
have been formed after all the same rocks of the local-
ity were produced.   He should recollect that the con-
glomerate or breccia beds may either have accumulated
round, and have been intermingled with, the once melt-
ed rocks, after having been shot up in the shape of
ashes, cinders, and stones, into the atmosphere ; be
formed by the action of water, in the case of sub-aqueous
volcanos ; or result from both these causes.   In cases
where the action of water has produced the arrangement
of the ashes, cinders, or stones, into beds ; mud, sands,
and stones, derived from non-volcanic rocks, may readily
be mingled with them in such a manner that the *angu-
lar* fragments of the trappean rocks may be associat-
ed in the same bed with the *rounded* pebbles of non-
volcanic rocks derived from a distance.   An observer
should therefore direct his attention to this point, and
should carefully notice if the fragments of trappean
rocks occur only around the masses of trap first no-
ticed, gradually disappearing as he recedes from them ;

to ; but a detailed notice of them in the text would only make
a complicated subject still more difficult to an inexperienced
observer.

the continuation of the conglomerates, if they exist, affording only pebbles or fragments of other rocks. He should endeavour to discover if there are any traces of volcanic sands among such associated beds; and as lava-currents, if sufficiently thick, may alter the rocks over which they flow, he should look for traces of such alterations in the beds immediately beneath any mass of trap associated with the marl, sandstone, or conglomerate beds, as the case may be, while he would not expect to find any alteration in those above, since the latter were accumulated after the lava-current ceased to flow from the absence of the necessary heat.

In order that the observer may not suppose we have dedicated too much of our limited space to a notice of circumstances which scarcely ever occur, because they have hitherto received little attention, we may state that in the neighbourhood of Tiverton, Silverton, Kellerton Park, and Crediton, in Devonshire, facts similar to those above noted are observable; and there seems good reason to consider that, in that district, volcanos existed at the period of the new red sandstone, which continued in activity while the lower part of that series was forming, and that probably such volcanos were situated in a manner, relatively to sea, not very unlike that of the island of Sciacca. Mr. Murchison has noticed phenomena which he considers may be well explained by volcanic action contemporaneous with the production of the grauwacke of part of Wales,* and we have done the same with regard to the same rock in Devonshire.†

* Proceedings of the Geological Society of London, 1834.
† Researches in Theoretical Geology, p. 384.

N

e. Although volcanic action—that is, the forcing out
of ashes, cinders, stones, and melted rock upon the
earth's solid surface by means of gases and vapours, and
the injection of melted rock into cavities and fissures,—
may have taken place from very remote periods, geo-
logically speaking, it does not follow that the propel-
ling gases and vapours have always been the same, or
that the rocks thrown out have possessed a like mineral
structure.   As the observer cannot learn how far the
propelling gases and vapours may have differed, he can
only direct his attention to the mineral structure of
those rocks of which the mode of occurrence is such
that they may readily have been ejected in the manner
of modern lavas.   He will often meet with amygda-
loidal rocks among these, and by attention to the di-
rection of the vesicles, now filled with agates, carbonate
of lime, or other mineral substances, he may learn that
in which the current of the trappean rock flowed, when
in a fluid or viscous melted state.   These amygdaloids
show that they have not, until consolidated, been ex-
posed to any great superincumbent pressure ; their pre-
sence therefore among other associated trappean rocks
is important.   We have seen some of this kind of
igneous rock, associated with greenstones among grau-
wacke, which were so vesicular that they must, before
foreign matter filled up the little cavities, have resem-
bled a light pumice-stone.   In one particular instance,
a few miles south from Launceston (Cornwall), the in-
filtrated matter, which happened to be carbonate of
lime, was so abundant, and the walls of the vesicles so
thin, that the rock has been successfully worked as a
limestone.

The observer should carefully note the various mineral characters of these supposed volcanic rocks of different ages, and take specimens of such as appear to be characteristic: he should also see if the mineral character be very different in the same locality. As these pages may probably pass into the hands of many who have not hitherto consulted works on geology, we should state that the chemical composition of an igneous rock may often be the same while its appearance differs, and that a piece of greenstone may be converted into a vitreous substance like obsidian by melting it and suffering it to cool rapidly in our furnaces ; — that such vitreous substance may be again reconverted into stone by such management, that after being again fused it should cool slowly ; and that in proportion as we can command slow cooling, we obtain a greater amount of crystalline structure. In proportion, therefore, to the crystalline structure of igneous rocks of the *same* chemical composition, may an observer assume the greater length of time for their cooling, and consequently conditions necessary to produce this effect.

f. The observer must not infer, because a trappean rock has been once full of vesicles, the infiltration of foreign matter into which has now converted it into an amygdaloid, that it, and any other trappean rocks associated with it, have necessarily been ejected in the manner of lava from a volcanic vent ; for if it formed the upper portion of a trappean rock, thrust up in mass, either fluid or viscous, from beneath, it might readily take the vesicular character when the superincumbent pressure was insufficient to prevent any gas or vapour. disseminated through the rock, from expanding.

N 2

g. We now come to the consideration of those igne-
ous rocks which neither in themselves, nor in their ge-
neral mode of occurrence, present us with any evidence
of their having been ejected in the manner of lava from
a volcanic vent : on the contrary, the evidence respect-
ing them tends to show that they have been thrust up-
wards among other rocks, in a state varying from con-
siderable liquidity to a viscosity approaching solidity,
and often in large masses.   Let us, for instance, take
the granites properly so called, and clearly intruded
among other rocks.   Hitherto nothing has been ad-
duced to show that these granites have been ejected
from anything resembling a volcanic vent, while there
is much to render it probable that they have been thrust
upwards in great masses, displacing other rocks, which,
when stratified, are often folded up or contorted around
them.   The same may in numerous cases be said of
masses of serpentine, diallage rock, various porphyries,
greenstones, &c.   By this statement we merely wish to
place before the observer that which may be fairly de-
duced from known facts.   We should depart from the
course we have traced for ourselves in these pages if we
attempted to bias his opinions by this or other infe-
rences ; he should therefore only receive such as are
given conditionally, until his own researches may en-
able him to judge how far they may, or may not, be
correct.

h. When an observer has a mass of granite, serpen-
tine, diallage rock, porphyries, greenstones, and the
like, before him, he should endeavour so to conduct his
researches, that while he attentively considers all those
circumstances which might lead to the inference that

they have flowed from volcanic vents in the manner of lava-currents, or that they have been thrown in masses, he should at the same time note if there be any veins shooting, as it were, from the main body of the igneous mass into the adjoining rocks ; and if so, whether such veins appear to fill up rents and fissures produced in the latter. Due care should be taken to notice the gradual change of mineralogical structure in such cases ; it being borne in mind, that if there be good evidence to show that the matter of the igneous mass has been forced into crevices and fissures in the pre-existing and adjoining rocks, the same chemical compound, which may appear large-grained and highly crystalline in the main mass, may readily form a more compact substance towards the termination of a vein outwards ; the simple reason being that, in the latter case, the compound would be exposed to conditions under which it would cool much more rapidly than in the principal mass. Specimens of these changes are always desirable for the purpose of analysis.

i. We may here again call the attention of the chemist to the great assistance he may render to geology by the analysis of portions of rock. We have elsewhere * calculated certain differences and resemblances which may exist in the chemical composition of various igneous rocks : as, however, such calculations are mere approximations, which may be more or less close according to the correctness of the data on which they are founded, we require more direct evidence of such differences or resemblances — and this can be best afforded by the experienced chemist. There can be little doubt

* Geological Manual, *Art.* Unstratified Rocks, 3rd Ed.

that igneous rocks, composed chemically of the same
substances, have often been distinguished by names
which would lead many to infer that they were not, as
they are, mere modifications produced in the same mass
of matter.   Let us, for instance, take a compound of
substances forming the minerals named hornblende and
felspar, so that when the two minerals can be properly
developed they each constitute one half of the rock.   If
this compound be exceedingly fine-grained, it would
very frequently be termed basalt ; if the minerals were
well developed, a greenstone ; and if so developed as
to constitute a large-grained rock, a sienite,—at least,
the latter name is often applied to such a rock.   Again,
if the same substances should so arrange themselves
that a mineral shall occur in a perfect, or nearly perfect,
crystallized state, disseminated in a base composed of
the remaining chemical substances, it would be termed
a porphyry.   These changes in the mineral structure of
the igneous rocks should engage the attention of the
observer ; and he will not unfrequently find that they
take place in very limited distances in the same mass—
one which has evidently been ejected or thrust up at
the same time.   Specimens illustrative of such changes
are valuable for the purpose of analysis, and therefore
should be collected with care.

   k. In dykes (p. 30), the observer should direct his
attention to the various changes of structure that may
be noticed in them.   It has been found that the outer
parts of dykes, composed of greenstone, sometimes pass
into serpentine, when the rock traversed is a limestone.
The passage of serpentine or diallage rock into green-
stone is also frequent when the former occur in large

masses.   These and similar points should not be ne-
glected.

l. The observer must in a great measure be guided,
in examining the occurrence of igneous rocks relatively
to each other and to those of aqueous origin, by the kind
of country he may be in ; and as this varies exceedingly,
it would be difficult to direct him how to act. He should,
however, particularly direct his attention to any evidence
there may be of the igneous rocks having cut through
or disturbed the district generally, or of their having
been injected among the strata or beds of pre-existing
rocks.   It must frequently have happened that igneous
rocks, discharged through fissures, or more or less exten-
sive vents, have flowed over the then existing solid sur-
face, and that the whole has been since covered by
some rock of aqueous origin.   Let us suppose that in
the annexed section (Fig. 128), *a b* is an igneous rock,

Fig. 128.
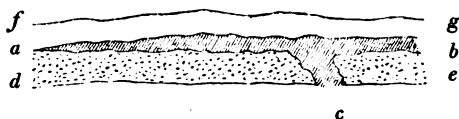
which has been ejected through the vent *c*, so that it
overflowed the surface of the pre-existing rock *d e ;* and
that after the consolidation of this igneous rock, the
aqueous deposit *f g* was formed upon it.   Now, as the
same general appearance might be exhibited if the ig-
neous rock *a b* had risen through *c*, and meeting with
considerable opposing force from the rock *f g*, took a
line of less resistance, which we will suppose was that
between the rocks *c d* and *f g*, so that it became in-

jected between them ; it is necessary that the observer
should minutely notice the condition of the under sur-
face of *f g* and the upper surface of *d e*.   If these sur-
faces both exhibit effects which may fairly be attributed
to the action of the heated rock upon them, or frag-
ments from both be included in *a b*, then it may be in-
ferred that *a b* has been formed after *d e* and *f g*, and
has been injected between them.   If, on the contrary,
the upper surface of *d e* alone offers any appearance of
having been acted on by heat, and that the lower sur-
face of *f g* perfectly conforms to the upper surface of
a b, little lines of structure, or of stratification, showing
that *f g* has moulded itself upon a pre-existing surface
of *a b*, perhaps even containing small fragments of the
latter, it may be inferred that *a b* is an older rock than
f g.   If, now, *f g* and *d e* be two known rocks of a
series, the relative age of *a b* will be also known.

m. To judge of the relative date of igneous rocks,
when sections are somewhat obscure, requires care. Let,
in the annexed section (Fig. 129), *a b* represent the

Fig. 129.
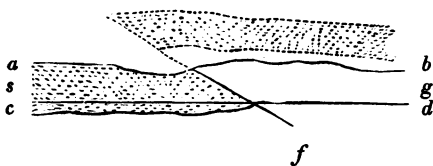
surface of a country ; *c d*, another line, beneath which no
sectional view of the rocks can be obtained ; *s*, some
supracretaceous sandstone; and *g*, granite:—it might at
first view be assumed, that the granite had overflowed
the supracretaceous rock, and was consequently more

modern than it. In the case before us, the inference
would be incorrect; for the granite may have been of
the oldest kind, covered, as all older rocks may be, by
one formed long posterior to itself; the apparent super-
position having been caused by the fault f, which is
by no means more inclined than some faults are, and
the subsequently produced surface having been so
formed as to give the false appearance of superposition
in this locality. We give this illustration, not because
such facts may often occur, but to place the observer on
his guard, when important inferences relatively to the
date of rocks may be drawn, so that he employ consi-
derable caution. The obvious course, in the case of the
illustration before us, would be to search for evidences
of a fault between s and g, and endeavour, either from
natural or artificial sections, to see if any continuation of
g may be obtained beneath s, either in the prolongation
of the surface line of junction between the two rocks,
or by at once passing through s in search of g.

n. It being commonly supposed that there has been
a change, viewing the subject on the large scale, in the
chemical character of the igneous rocks, producing a
corresponding change in their mineralogical structure,
between the older geological periods and the more mo-
dern,—that is, that the rocks ejected and thrust up-
wards in a melted state were not formed of precisely the
same mineral substances in the earlier conditions of the
earth's surface, as at more recent epochs,—the observer
should be careful not to neglect opportunities of ob-
taining the relative ages of the igneous rocks whenever
they present themselves. This is to be accomplished
by noting their mode of occurrence relatively to the

N 5

rocks of aqueous origin. When it can be determined
that they, or rather that certain of them, repose upon,
or cut through, any rock of which the relative age is
known, it follows that the particular igneous rocks
which do so are more modern than those aqueous rocks
on which they rest or through which they cut. When
they are quietly covered by aqueous rocks of known re-
lative date, they are known to be more ancient than the
latter.

XXV. *Altered rocks.*—Although there are few
rocks of mechanical origin which have not been in some
degree modified in their structure since the period of
their original deposit,* the term *altered rocks* is at
present exclusively applied by geologists to that modi-
fication of mineral structure which has taken place in
rocks, since their production, through the agency of
heat ; it being understood that the heat has never been
sufficiently intense to produce fusion, and, therefore, if
the rock has been stratified, that it retains that struc-
ture, the alteration having been solely produced in the
position of the component particles relatively to each
other.

a. When the observer suspects that he has altered
rocks before him, his first care should be to trace those
that he may consider such to situations where their
characters shall be altogether unequivocal. Let us sup-
pose that the annexed sketch (Fig. 130) represents a
map of a district, *e f* being a line of coast, and that the
observer is passing along it from *f* to *e*. Let us further
consider that *a* is granite, and that arriving at *h*, he
finds a rock in contact with it which at first sight he

* See Researches in Theoretical Geology, p. 91.

Fig. 130.
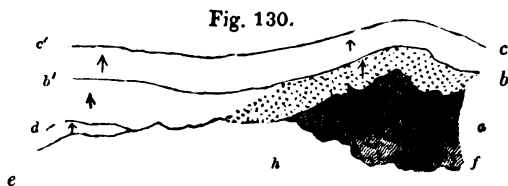
considers to be gneiss, but upon reflection suspects may
be an altered rock, from the general geological charac-
ter of the district.　He might first trace the supposed
gneiss round to *b*.　We will imagine that he does so,
and finds its characters constantly the same; and, more-
over, discovers a fossiliferous rock, *c*, resting upon it. He
will still continue in uncertainty, because he has follow-
ed a direction where, if the rock were altered, the condi-
tions for producing this alteration would be the same ;
and therefore he would learn little more than if, when
at *h*, he had gone into the interior and ascertained the
kind of rock which rested upon the supposed altered
rock *b*, the dip of the latter being in that direction.

　The course of the observer should be in the direction
of *e*, away from the granite, which for the sake of
illustration we must suppose not to be continued, even
beneath the sea, in that direction.　He must now care-
fully search for changes in the mineralogical character
of the rock he is tracing, and be on his guard against
the substitution of another rock in its place in the line
of strike.　To illustrate our subject, let us consider
that he gradually observes the character of gneiss to
pass away, and that, as he recedes from the granite, the
rock passes into an argillaceous slate.　He should en-
deavour to learn if this slate be fossiliferous : if it be

so, he may set down the rock *b* as altered when in con-
tact with the granite.   This necessarily implies that
the slate is an older rock than the granite, and that the
latter has been brought into contact with the former in
a state of fusion or great heat.   Hence, still further to
convince himself that an alteration in the rock *b* has
been caused by the granite, he should carefully search
for evidence of the intrusion of the latter into the
former.

In the foregoing plan (Fig. 130) we have supposed
the altered rock to be included, in the direction *e*,
between two rocks, *c′* and *d*.   Now, if these be known
rocks of a series, either from being fossiliferous or
from other circumstances, the relative age of *b b′* will
be known, and the observer will learn that such rock
has been altered, and puts on the deceptive appearance
of gneiss, when in contact with the granite *a*.

The observer should in all cases, whether on the
small or large scale, have good evidence that a rock is
altered, by tracing it to situations where it is unaltered,
or by finding organic remains in it which are known to
occur in given rocks of the district, or in those of a
known series, the proximity of an altering course, within
a reasonable distance, being sufficiently evident.

b. It is not enough that a given rock merely changes
its character,—such, for instance, as from mechanical to
crystalline,—thence to infer that the crystalline are
altered portions of the other parts.   It may readily
happen that, in certain extensive deposits, one part is
formed mechanically and another chemically, part of
the latter being highly crystalline.   Let the arc *a b*
(Fig. 131) be the level of the sea over an extensive

Fig. 131.
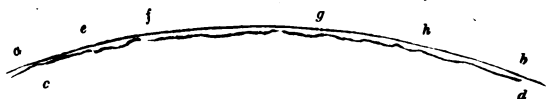
area, and *c d* the solid bottom beneath it.   There will
be no difficulty in conceiving that a contemporaneous
deposit effected on the latter may be sand at *e*, mud at
f, common limestone at *g*, and crystalline limestone at
h ; or that there may have been great variations in this
respect throughout the whole distance.   Hence, if by
accident the crystalline limestone were formed upon a
pre-existing mass of igneous rock, and were subsequently
elevated above the level of the sea, it might, without
sufficient care, be assumed that such crystalline struc-
ture was produced by the former heat of the igneous
rock, and such crystalline rock an altered one.

In the cases of certain dolomites (a compound of
crystalline carbonate of lime and carbonate of mag-
nesia) and crystalline limestones, this caution is par-
ticularly necessary ; since, though there is often suf-
ficient evidence to show that rocks possessing these
characters are altered, there is also evidence that others
of a similar character have been originally formed as we
now see them.

c. When the alteration of rocks is a fair inference
from the facts noticed, the observer should pay great
attention to the kind of alteration produced, taking
specimens which are illustrative, more particularly for
the purpose of chemical analysis, in order that it may
be seen whether the same component parts are present

in all, or whether foreign matter has been introduced
into that of the original rock during the process of
alteration.   When, moreover, several beds, varying in
mineralogical structure, are cut by the same mass of
igneous rock, and they have all been altered, he should
attend to the relative alteration of each, noting how
far the original mineral structure has modified the
amount of distance to which the alteration may be
traced in each.   Let *a*, in the annexed plan or section
(Fig. 132), it is immaterial which, be an igneous rock

Fig. 132.
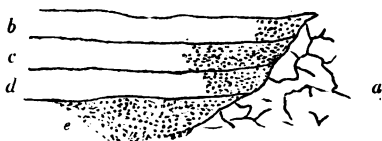
which has cut through several beds or rocks, *b*, *c*, *d*, *e*,
and let each of the latter differ mineralogically from the
other ; then he should note whether, due allowance be-
ing made for the curves of the junction line between
the intruded and pre-existing rocks, they are altered to
various distances,—and if so, carefully distinguish the
mineral structure of each.   We have above supposed
and shown by dots, that *e* has been altered to the
greatest distance, and *b* the least.

   d. In all cases of dykes composed of granitic, trap-
pean, or common volcanic rocks, it is desirable that
search be made in the adjoining rocks for alterations in
their structure.   This often takes place, and is disre-
garded because the alteration so produced is on the small

scale. It is, however, highly instructive; and it is desirable that the observer should see if any reciprocal action has been produced upon the matter of the igneous rock itself. We have already stated that such action may be found under certain conditions, and it probably takes place more than has hitherto been remarked. We have observed changes on the large scale which would seem to require this kind of explanation.

e. It must not be supposed that alteration of rocks, in the sense above noticed, has been confined to those of aqueous origin : they may sometimes be found where one mass of igneous rock has cut through another and pre-existing mass. The changes then produced are often highly interesting, and such as the observer should by no means neglect.

XXVI. *Metalliferous veins.*—In accordance with the usual custom, we confine the above name to those veins which contain metals employed for useful purposes. The definition is, however, far from good, since the ores of metals—such, for instance, as iron pyrites—occur alone in situations illustrative of at least some kinds of metalliferous veins. It is by no means our intention to enter at length upon this complicated subject ; we merely desire to call the attention of the observer to one or two prominent points.

a. It being considered that many metalliferous veins are but the fractures usually termed faults (p. 199), and that the ores of the various metals found in them have been subsequently introduced, the observer should direct his attention to such circumstances as would characterise the relative position of the sides of the vein and its contents, if such were the case. He will search

for evidence of movement in the sides, marks of friction, fragments of the adjacent rocks in the fissure, and other circumstances previously noticed (p. 200). He would do well, when opportunities offer, to study the occurrence of iron pyrites in common faults, and note how far there may be any difference between such mode of occurrence and that of the ores of copper or of other metals, as the case may be.

b. It has been noticed in some countries, and we have had occasion to remark the same thing, that a metalliferous vein or lode ran parallel, or nearly so, to a great fault, and that the former appeared like a crack produced when the neighbouring great fracture or dislocation was formed. This also is a circumstance to which the attention of the observer should be directed.

c. Metals also occur in a kind of network formed of numerous strings of ore, which cross each other in all directions. These have by some been considered as contemporaneously produced during the consolidation of the rock ; while others regard them as a multitude of small cracks formed in the containing rock during consolidation, into which the matter of the ore was subsequently infiltrated. The observer should without bias endeavour to note the various facts connected with such modes of occurrence.

d. Metals, again, are disseminated through rocks in grains, which are for the most part crystalline. The oxide of tin is thus sometimes disseminated in granite, and gold has been so found in some porphyries. In such cases, the observer should be careful to note whether the disseminated metals appear to have crystallized out in the manner of iron pyrites in some trap rocks,

or in the manner of the same substance in mechanically produced marls, clays, and slates.   He should also be careful to ascertain whether the grains may have been the detrital portions of pre-existing metalliferous veins, such grains having been washed onwards with the other parts of a mechanical rock until finally brought to rest with them.

e. As it every day becomes a more prevalent opinion, from an increased stock of facts, that the metals in veins have been derived from the rocks which contain them, the observer should direct his attention to the condition of the containing rocks in the vicinity of the veins, noting if there be any difference in their mineral structure near the veins, and at some little distance from them.   In cases where such differences are observable, specimens are desirable, more particularly for the purpose of chemical analysis.

f. As the same lode or metalliferous vein is observed in all mining districts to vary more or less, viewing the subject on the large scale, according to its range through different rocks, or even through the same rock, when the latter varies in mineral composition, or even in hardness, the observer should carefully note the kind of changes thus effected, and remark how often a similar mineral structure is associated with a similarly characterised vein.   By obtaining a mass of classified facts of this kind, more insight into this subject may be eventually obtained than we now possess.

g. Remarkable facts are often observable at the crossing or intersection of two or more metalliferous veins, more particularly with regard to the kind of metals found, and to their association, as also as respects

the shifting of the general planes of the lodes or metal-
liferous veins.   In the latter case, particular attention
should be paid to any resemblance there may be be-
tween such facts and the crossing of faults of different
ages, the continuity of one set of faults being then
destroyed by the shifting caused by the crossing of an-
other set.

h. It having been frequently remarked that metal-
liferous veins are abundant at the junction of an unstra-
tified with a stratified rock, when the former has been
intruded among the latter, the observer should care-
fully note, when metalliferous veins traverse both rocks,
the distances to which particular characters of the lodes,
and the abundance of ore in the veins, extend on either
side of the junction line between the stratified and un-
stratified rock.

PART III.

APPLICATION OF GEOLOGY TO THE USEFUL PURPOSES OF LIFE.

I. *Agriculture.* — IT would be difficult to find an intelligent farmer, in a district where rocks of variable mineralogical characters occur, who does not, to a certain extent, practically know that the value of each soil respectively depends upon the kind of rock beneath it. He may not know, and scarcely ever does, why this happens; but the fact itself is familiar to him. Now, it is precisely a knowledge of why this happens which enables a geologist, acquainted with the mineralogical structure of a given rock in a district, to state that the soil formed upon it will, under equal circumstances, better support one kind of cultivation than another. In some cases, the lines separating particular kinds of cultivation are precisely those which separate two rocks beneath them; the agriculturists having found, from experience, that the two soils above these rocks will not support the same cultivation with equal advantage. The common country division of soils into heavy, light, cold, and the like, depends upon the kind of rocks beneath them.

Natural soils are merely decomposed parts of the subjacent rock, mixed with the decomposed portions of vegetable substances, which have grown or fallen upon it, and with a proportion of animal substances derived from the droppings of creatures which have fed upon

the vegetation, from dead insects and worms which
once inhabited the surface, and from the decomposition
of animals that have perished on the land, and which
have not been altogether removed by those quadrupeds,
birds, and insects that act as natural scavengers.

The permanency of natural soils depends upon the
relative positions they occupy (such as whether they
are formed on the steep slopes of hills or on level
plains) ; upon the porous or impervious character of
the supporting rock as regards water (whence the dif-
ficulty or facility with which the soil may be washed
away during rains) ; upon the climate generally of the
locality, more particularly as regards the quantity of
rain which may fall in a given time ; and upon the kind
and amount of vegetation upon them, by which they
are more or less protected from removal according to
circumstances.

Although some plants grow without having their
roots plunged in the soil, this, as is well known, is not
the case with vegetables generally, nor with those culti-
vated by man, either as food for himself, or for those
creatures which he has domesticated.   If we consider
the leaves as the lungs, the stems as the bodies, and
the roots as the mouths of plants, it will be evident
that a plant cannot obtain the same food from soils
which differ materially from each other.   As animals
perish, draw on a miserable existence, or thrive, accord-
ing to the food given them, so do plants; and if the
agriculturist force a given kind of plant into a situation
where it cannot obtain the nourishment for which its
various parts were constructed, it cannot thrive.   Now,
as one kind of food is proper for some animals and not

for others ; so, with plants, the soil which will nourish some is improper for others. Hence it becomes necessary that the agriculturist should know the kind of soil best suited to each plant he may cultivate ; and as the character of soils mainly depends upon the rocks of which they are chiefly the decomposed portions, a knowledge of the mineralogical structure of these subjacent rocks, and of their general mode of occurrence, can scarcely be less essential to him.

The mineral substances forming masses of rock are not very numerous ; and while some decompose readily, others retain their original structure. Both characters are often highly valuable in a soil ; the undecomposed portions keeping it *open,* as it is termed,—that is, allowing the free dissemination of air and water,— while the decomposable parts unite in various ways with or modify the food of the plants. Thus, a due admixture of silica in the shape of sand is often highly valuable, while a proper allowance of carbonate of lime tends to neutralise any acetic or other noxious acid which may be present in a soil, that is then technically termed *sour.* The name *humus* has been given to the vegetable and animal matter mixed with the mineral ingredients of a soil. To this important part of a soil a rock can only indirectly contribute ; but there will be little difficulty in conceiving, that the greater the ability of a rock to afford a decomposed mineral mixture which should suit the greater quantity of vigorous and luxuriant plants, the greater would be the probability of a larger amount of humus in the superjacent soils. Not only would the probability of a larger amount of vegetable humus be greater, but the chances of a larger

amount of animal humus would be increased from the
greater mass of insects, reptiles, birds, and mammifers,
which would either feed upon, or shelter themselves
among, the more luxuriant vegetation.   This *à priori*
reasoning is borne out by facts ; since it is found, that
under equal circumstances as to climate and other con-
ditions, a mineral mixture which suits a larger amount,
or the more luxuriant parts, of a given vegetation, will
be that associated with the greatest relative amount of
humus in a natural soil.

We must refer to the article on AGRICULTURE for
the connexion between particular soils and the plants
grown upon them, and content ourselves by noticing
the dependence of the character of the soil upon the
subjacent rock.   No one would expect that *all* the
plants cultivated by the agriculturist could grow equally
well upon the chalk of eastern England, on the red
marls and sandstones of the central and western coun-
ties, and on the grauwacke of Devon, Wales, and
Cumberland.   We should, however, observe, that it
is upon the mineralogical structure, not the geological
age of rocks, that the barrenness or fertility of the
superjacent soils depends.   Taken, however, as masses
of matter, the mineralogical structure of rocks is suffi-
ciently constant throughout moderate areas, so that if it
be known as respects one part of it, the other parts will
not be found to differ materially.   Hence, the agricul-
turist who examines a good geological map, compris-
ing a moderate area, may feel assured that the respective
soils, upon the various rocks traced upon it, will possess
the same general characters under equal circumstances. If
geological maps be, as probably they will be, improved

by the insertion of symbols or signs in different places, showing the mineralogical structure of the rocks at such places, the information afforded to the agriculturist will be still more complete.

a. As a soil, composed of the same mineral substances, is of very different value to the agriculturist according as it is either wet or dry, the observer should direct his attention to those circumstances which render it either the one or the other.   Disregarding for the present the general surface-drainage of a country, the dryness of a soil depends, under equal evaporation and supplies of rain, upon the facility with which its particles permit the percolation of water downwards, and this facility upon the kind of rock beneath, as above noticed.   Sandstone rocks generally, as might be expected, afford a dry soil.   This, however, is not the case with all arenaceous rocks.   In some, the mineral matter, cementing the particles of sand together, is so aluminous and abundant, that when the rock is decomposed, the clayey matter overpowers the sand, and a heavy tenacious soil is the result.   When the observer finds that the subjacent rock of a dry soil is porous and sandy, his remedy for this kind of soil, if it be desirable, will be to do something which shall retain moisture in the soil itself as long as may be convenient; since, once arrived at the subjacent rock, it will be absorbed freely by it.   Some addition must therefore be made to the soil, either of a substance which readily absorbs moisture from the atmosphere, to be consumed by the vegetation, or of a mineral substance which shall bind the particles of the soil more firmly together, so that, in a given time, a much less quantity

of water shall pass downwards to the absorbing rock
than if no such mineral substance had been added.
Soils thus circumstanced may be considered as well
drained beneath.

When a dry soil is the produce, by decomposition, of
a rock which does not freely absorb water, additions to
it, for the purposes of rendering it more moist, require
very great care.   The observer will generally find such
soils shallow, and liable to be washed away by rains.
The rains run speedily off where the physical features
are favourable, and the soil soon becomes dry from
evaporation.   It is not a little interesting to observe
the excellent effect produced on such soils by the loose
stones, not unfrequently scattered over them.   These
retain moisture in the soil by preventing the evapora-
tion which would otherwise take place ; and it is often
not a little curious to note the differences of corn-crops
on two adjacent farms, when the occupant on one has
removed the stones, and the other has allowed them to
remain, the advantage being so greatly in favour of the
latter.   With regard to scattered stones on dry soils.
generally, it may be stated, that there are some of the
latter so porous that sufficient moisture would not
remain in them to reward the agriculturist for his
labour, if they were not abundantly covered with scat-
tered stones.   In high lands they also serve to con-
dense fogs and low clouds, and thus add to the mois-
ture of the subjacent soil.

   b. A wet or heavy soil mainly depends upon the
quantity of clayey matter afforded by the rock beneath
it.   The latter is very often, under such circumstances,
a clay itself, or an argillaceous rock readily converted

into such a substance by the addition of sufficient mois-
ture. The soil, therefore, is held up by a sheet of
rock impervious to water, and the necessary effects must
follow. Such soils are, however, scarcely ever good in
themselves; but a good soil may be, and occasionally
is, supported by a bed of clay,—the good soil being due
to the decomposition of a bed or stratum, the mineral
character of which was of the proper kind. The bed of
clay, or other bed impervious to water, will, if the soil
be not sufficiently thick, cause the latter to be wet, and
unfit for purposes to which it might otherwise be de-
dicated. The observer should ascertain the thickness
of the clay or other bed, and the nature of the rock
beneath it. If the bed of clay, supposing it to be
such, is not too thick, and the stratum beneath be
porous, he will be able, from the geological and phy-
sical characters of the country, to judge whether it may
be better to pierce through the clay bed in many
places, leading radiating drains to the holes thus form-
ed, or drain generally in the usual way. When there
is an extensive and elevated table-land, here and there
cut by deep valleys, the former might be the cheaper
plan, though probably it has never, except accidentally,
been carried into practice. We have seen parts of a
table-land formed of a fair though gravelly soil, *a*,

Fig. 133.

resting upon a tenacious clay, *b*, drained naturally
upon this principle, by means of pinnacles of chalk, *c, c,*

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which pierced through the clay in several places, and
entered the gravelly soil above.   The portions of soil
above and near the chalk pinnacles were kept fairly
drained by the well-known property of chalk readily to
absorb moisture, while those portions of the soil which
were too far from the draining influence of the pinnacles,
were wet and heavy.

If, upon the same principle, an agriculturist should
find it difficult and costly to drain a soil, placed under
the conditions above noticed, in the usual manner, and
that the part to be drained is situated as at a (Fig. 134) ;

Fig. 134.
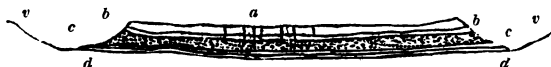
if he can deliver the water into the porous rock c c,
by drilling numerous holes in the clay bed b b, such
water would tend to percolate through the bed c c,
and be delivered in springs into the valleys, v v, if
c c be supported by a bed, d d, impervious to water.
If the water be not stopped by such a bed, then it
will continue to percolate through the inferior mass in
the usual manner.   To know that the proper conditions
obtain, necessarily requires competent geological obser-
vation.

$c.$ When an observer finds a heavy soil produced by
the decomposition of hard rocks, such as certain sand-
stones and slates of the grauwacke series, or others of
the like mineralogical structure, be their geological age

what it may, he should direct his attention to the stratification of the rocks affording the principal materials for the soil, since the practicability of ameliorating the latter much depends upon this circumstance. Let us suppose that the annexed section (Fig. 135) repre-

Fig. 135.

sents the stratification of a series of rocks affording a heavy clay soil, so that the beds are horizontal at *a*, contorted at *b*, and dip at a considerable angle at *c*. Now, supposing them to be, as they generally are, nearly impervious to water as beds, and that the soil is attempted to be made lighter by artificial means over the whole surface *a b c*, very different success will attend the experiment at *a* and at *c*, because a water-supporting surface will still continue beneath the soil at *a*, while the interstices between every bed at *c* will serve to drain the land. Consequently, if the soil be so lightened that water can freely percolate down to the edges of the beds at *c*, due care being taken to lay open such edges by lines of drains, so that the upper portions of the interstices are not choked by particles of clay, the soil may be rendered far more dry than before. If an observer direct his attention to two soils derived from similar rocks, the one situated upon nearly horizontal strata, and the other upon the edges of highly inclined beds, he will frequently perceive that the

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former may be heavy and the latter comparatively light, for the simple reason that one is naturally drained and the other not.

d. Although a geologist may feel satisfied that a porous rock is situated beneath a water-supporting stratum, near the surface of land, the agriculturist can scarcely be expected to be aware of the structure of the rocks beneath the few feet to which, in his deepest ditches, he is in the habit of working. He may, however, greatly advance himself in a knowledge of circumstances that may often prove highly valuable to him, by consulting good geological maps, constructed on a large scale, which will give him the *surface* of land occupied by any given rock, and then turn to the sections which ought to accompany such maps, which will show him how the rocks occur relatively to each other beneath the soil. Let him now consult the memoirs written to illustrate the map and sections ; and by carefully combining the accounts given of the structure and composition of the rocks, as noticed in the memoirs, first, with their relative position as shown in the sections, and secondly, with the portions of surface occupied by each respectively, as shown by the maps, he will obtain, without embarrassing himself with those questions which relate to the higher branches of geology, a stock of knowledge respecting the rocks beneath the soil in given districts, which he can readily turn to good account in his management of land, even when the authors of the maps, sections, and memoirs may not have constructed the former, or written the latter, with reference to any advantage agriculture could derive from geology.

e. Even a knowledge of the faults (p. 199) which frequently traverse countries may be turned to account by an agriculturist in the drainage of land. Some of these fissures or dislocations are pervious to water, and act as main drains to portions of country, as is well known to their cost by miners in metalliferous districts. Others are filled with substances, such as clay, which prevent the passage of water on one side of the fault to the other; a circumstance highly valuable in some coal districts,— for by the intersection of several of these faults, masses of strata are enclosed by them, and if the water be pumped up by proper engines from such masses respectively, the coal-worker has only to contend with the water in any mass on which he may be occupied, a supply from other adjacent masses being cut off by the surrounding faults. It is obviously from the first kind of faults that the agriculturist can derive any advantage in the shape of drainage. Faults may be made to assist the drainage of elevated table-lands, even when their continuations across the valleys, which may cut into such table-lands, afford an abundant supply of water to the surface, as will be seen by the annexed diagram (Fig. 136). Let the line *a b* be a

Fig. 136.
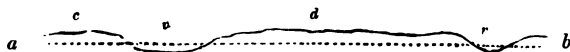
level, at which a fault contains an abundance of water which is readily discharged upon the surface of the valleys *v v*, that cut the surface of land beneath this level. Then if *c d* be table-lands into which the

fault cuts upwards, the water conducted into it on
such table-lands, either naturally or artificially, will
tend to percolate downwards to the level, whatever its
relative height may be, at which a quantity of water is
sustained in the fissure, and which we have supposed to
be represented by the line *a b*.

f. As the nature of a soil so materially depends
upon the mineral composition and structure of the rock
beneath it, an agriculturist should be alive to the ad-
vantages he may derive from a mixture of the materials
of two or more rocks in producing a soil which shall
be better than that naturally found on either respec-
tively. This sometimes is done when that kind of
rock commonly known as *marl* is near some soil to
which it is considered a valuable addition, the marl
being taken from the marl rock and distributed over
the soil. In this the agriculturist does no more than
add mineral matter to his soil; which, in point of fact,
had not been afforded either at all, or in the proper
quantity, by the decomposition of the rock beneath it.
Many other valuable mixtures than these might be
made with the materials of rocks, frequently adjacent
to each other, either as regards the surface of land,
or depth beneath such surface. Some of these mix-
tures are so obvious, that, while examining the geolo-
gical structure of some countries, we have been sur-
prised that the accidental mixtures of the component
parts of two adjacent rocks at the lines of their junc-
tion, and which demonstrate by their advantages the
superior fertility upon them, have not induced agri-
culturists to inquire a little into the cause of them.

Carbonate of lime cannot naturally exist in soils

derived from rocks which do not contain it,—at least
any portion found in them must be derived from the
remains of snail-shells and the like.   Now, the rocks
which do not contain carbonate of lime are very nu-
merous, particularly among a variety of the older
series; and as the presence of carbonate of lime in a
soil is so valuable to the agriculturist, it is obviously
a mineral substance which it becomes his interest to
add to one that contains little or none of it.   The
application of lime in its burnt state to soils is so com-
mon, that we should not notice the fact if we had not
often witnessed farmers dosing their land to excess
with it, without the smallest regard to any other mi-
neral ingredient, or to those proportions of such in-
gredients which have been found to answer best with
different kinds of cultivation.   Indeed, as far as re-
gards the large majority of farmers, they seem to con-
sider that all plants are to be fed alike, and that
what is good for one must be so for another.*

* A curious example of a general practice of adding mineral
matter to a soil, without the smallest conception on the part of
those who do so of what they add, is to be found in the north-
western portions of Devonshire.   The rock of the district is grau-
wacke, composed of compact arenaceous beds mixed with slate, in
the greater part of which there is no carbonate of lime, while silica
and alumina are abundant. The district generally is far from fertile,
and makes little return to the farmer.   Now, it is the general prac-
tice in that country to bring sand from the sea-coast, often many
miles distant, to mix with the soil, by which the productiveness
of the latter is increased.   It is also the general belief that the
sand benefits the soil by loosening it, though the farmers are aware
that the same quantity of other kinds of sand, which may also be
obtained on the coast, will not produce the same good effects.   The

g. Given rocks, viewed mineralogically, affording like soils by their surface decomposition, the observer should direct his attention to the various plants which flourish best on each respectively, according to the climates in which they may be situated. This study, which may be termed geological botany, has already been advanced by many local researches, but hitherto no very extended views have been founded upon them. It can scarcely be otherwise than one in which agriculturists should be deeply interested. In this way, some plants are found to be of little value when cultivated off given rocks. The pimento or allspice tree of Jamaica may be taken as a good instance of this fact, since it is only profitably cultivated upon the white limestone formation of that island. Again, other kinds of cultivation, though they may to a certain extent succeed on several kinds of rock, are found to afford far more profitable returns upon one or two in particular. Even alluvial soils differ in value, as might indeed be anticipated, since patches of them are respectively formed of the wash, if we may use the expression, of districts which may, and generally do, vary as to the rocks of which they are composed.

Some soils are often underrated because they will not readily afford good returns as regards all, or the greater part of, the cultivation attempted upon them.

fact is, that the sand brought chiefly, and sometimes almost entirely, consists of carbonate of lime, being the triturated fragments of sea-shells thrown on shore by the breakers; and thus the farmers add, without being aware of it, a mineral substance to the land in which it was deficient, and which it required to render it somewhat fertile.

The granitic is often a despised soil in the West of England, and undoubtedly it is bad for many kinds of cultivation,—but it is found that potatoes will thrive well in it. Thus the granitic country round Moreton Hampstead in Devonshire affords the best potatoes for the Exeter market, notwithstanding there are so many localities in the district favourable to the growth of that plant. We will not, however, occupy more of our space with this subject. The connexion of the value of the soil and the kind of rock beneath it will constantly be forced upon the observer, and he has only to register and classify such facts to obtain a fund of valuable information on this head.

II. *Roads.*—That the expense of constructing a new road, or of maintaining an old one in good order, greatly depends upon the kind of ground under it, upon the facility with which proper stone may be obtained for it, and upon the stability of the various cuts which it may be found necessary to make in the rocks, is well known. It is not, however, so well known that these circumstances depend upon the geological structure of a country, and that a knowledge of this structure would enable those who possessed it to determine whether one line of new road would be more costly than another; whether, when it becomes a question to patch up an old line of road or construct a new one, the one or the other will be ultimately found least expensive ; and that some kinds of stone should be employed upon roads in preference to others, when several kinds can be readily obtained. The sums of money annually thrown away in this country from a want of due attention to the latter circumstance must, collectively, be very considerable.

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We have seen instances in which stone was brought
several miles for new roads, when a better material was
close at hand.   It might be true that no quarries were
opened upon the better material; but any person with a
little geological knowledge would point out the proper
places to do so.

Roads generally are planned with regard to little else
than levels and distances ; and if there be a small ad-
vantage in this respect between two lines in favour of
one, that line will be selected, though often a fair
amount of geological knowledge would be sufficient to
show that the expense, not only of forming, but also of
keeping up this road, will be far greater than for the
other.   Good geological maps are in this respect highly
valuable, as they enable those who have to decide upon
subjects connected with roads to see at once the kind of
rocks over which a projected line of road is intended
to pass.   They also point out the proximity of rocks
which may afford good materials for stoning either new
or old roads.

 a. In cutting through stratified rocks, it should be
recollected that lines of springs may be intersected
which may prove injurious to the road; and also that,
by inattention, a hard supporting stratum may be cut
through, and the road thrown upon a clay or other loose
substance, by which much unnecessary expense will be
incurred in order to render the bottom firm.   In all
deep cuttings to lower hills, the observer should note
the mineral structure of the rock cut through, so that,
when it becomes exposed to the atmosphere, the slopes
given to the sides may be found sufficient, and the
proper drainage of the road be preserved.

b. In choosing materials for roads, the observer
should recollect that the stones placed on them are ex-
posed, not only to friction, but also to the pounding or
crushing action of the weights which roll over them, and
consequently that a tough as well as hard substance is
required. Now, rocks differ exceedingly in these quali-
ties; and those persons who have paid attention to the
kind of stones thrown on roads must have remarked
how frequently hard stones are preferred by surveyors
and others, when tough materials were to be obtained
equally near and cheap. Thus, when flints from the
chalk and chert from the green sand are found as gravels
in some parts of the south-west of England, it is curious
to observe how frequently the former are preferred to
the latter. Rocks which are composed of substances of
unequal degrees of toughness, are greatly inferior to
those which are of the same texture throughout : thus
granites generally afford road-stones inferior to a great
variety of trappean rocks. The unpaved streets of
London, those which are commonly termed M'Adam-
ized, show how readily granite is pulverised when sub-
jected to continued friction and pounding from the con-
stant passage of horses and carriages over it. Such
roads soon become either dusty or muddy, according to
the weather. Trappean rocks have lately been import-
ed into London for the purpose of stoning some roads;
and no doubt those who have done so will soon find
that, though the trappean stones cost something more
in the beginning, they cost less in the end, since their
durability is so much greater than that of the granites.

Those granites in which the felspar is well crystal-
lized are the worst for the purposes of stoning roads,

since this mineral then soon crumbles under pressure, while the granites in which hornblende prevails and the felspar is more compact are the best. The trappean rocks vary considerably in their value as road-stones; even the same quarry will afford materials of different degrees of toughness. Some greenstones are particularly valuable in this respect, as also certain diallage and hypersthene rocks. When no better instrument is at hand, a large iron pestle and mortar may be used with advantage in ascertaining the relative toughness of stones. If an observer will take specimens of those intended for ex-amination, of the size of the stones usually thrown on the roads, and then proceed to pound them, taking one specimen at a time, he will soon obtain a rough esti-mate of their relative values. Machines for ascertaining the relative superiority of road-stones have been in-vented, and there would be no difficulty in constructing those which should show their relative degrees of tough-ness with considerable precision. By stoning a road with proper tough materials, we not only reduce the expenses of its maintenance, but also the annual amount of hindrance caused by the more frequent sup-ply of rough new stones, which tend so much to retard the progress of wheel-carriages, and add to the labour of the horses that draw them.

c. The difference in the durability of road materials, obtained from different beds of the stratified rocks, is so considerable, that those charged with their supply, in districts where such rocks prevail, should make them-selves acquainted with their strike and dip. The in-stances in which much unnecessary expense might be avoided, by this simple application of geological know-

ledge, are far more numerous than would readily be credited by those who have not directed their attention to the subject.

d. In all cases, whether of the stratified or massive rocks, the observer should be careful that the stones employed for roads are not taken from the upper or weathered portions of quarries, where they have been more or less exposed to atmospheric decomposing causes, and consequently are not so valuable for the purposes required as those taken from situations where these decomposing causes have scarcely been felt.

e. In cutting roads on the sides of hills, the observer should in many cases note the dip of the beds, and their general structure, if the subjacent rocks be stratified, with considerable care; otherwise much mischief may ensue. Let the annexed diagram (Fig. 137) represent

Fig. 137.
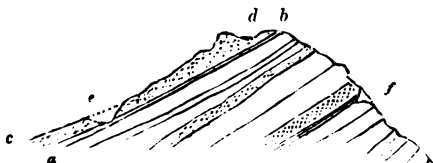
the section of a hill, composed of beds which dip in one direction. Let *c d* be a bed of sandstone resting upon a soft clay, *a b*. Now, if a cut, *e*, be made in the hill, the continuity of *c d* will be destroyed, and the part *d* will tend to slide down upon the cut *e*. If a cut, *f*, be made on the other side of the hill, and a similar arrangement of beds exist there, no such tendency of the upper to slide upon the lower beds will be produced.

Hence, not only in such instances as that above no-
ticed, but also in districts of certain slate and other
rocks, where the cohesion between the laminæ or beds
is slight, and the dip somewhat highly inclined, a pre-
ference should be given, when cuts are made for roads,
to those sides of valleys or hills, as the case may be,
where the strata dip inwards into the mass of the hill or
mountain, as at *f*.

III. *Canals.*—In projecting lines of canal, particu-
larly when tunnels are to be constructed, a knowledge
of the geological structure of the country is not less
necessary than in the case of roads.   The probability
of meeting with springs of water, the porous or imper-
vious character, as regards water, of the rocks to be tra-
versed, and the kinds of rock which will be encounter-
ed in cutting, may all in a great degree be foreseen
by those who have examined the geological structure of
the district.   Hence good geological maps will be found
of great value to those who are about to form canals.
They also point out the various mineral substances
which may advantageously be brought to the canal for
the purposes of traffic.   From a knowledge of this kind,
canals have been made to pass by or through tracts of
country where limestones, coal, or metals are discovered.

Canals, as is well known, are often found to be more
costly than was anticipated, from the simple fact that
some of the rocks traversed readily absorb water, and it
therefore became necessary to incur the expense of ren-
dering the canal-bed water-tight.   Where the supply
of water is limited, the presence of an extended line of
porous rock is a serious difficulty.   It is one, however,
which might sometimes be avoided by a competent

knowledge of the geological structure of the district traversed, for such knowledge would enable the engineer so to form his plans as to avoid the porous rocks as much as possible. It should be recollected that a knowledge of the rocks on the surface will not give that of those which may be cut into the line of a canal, unless it be coupled with such information, respecting the mode in which the rocks of the district occur, that the observer shall be aware of those kinds which will probably be found at given depths in different places. A fine retentive clay may exist on the surface and rest upon a porous sandstone; and therefore, in following the levels, the former may be cut through, and the canal-bed be based on the latter.

IV. *Wells.*—The geological observer will find no difficulty in applying his knowledge to the probability or improbability of obtaining water by means of wells in given situations. The most important are those named Artesian, which are perpendicular borings made into the earth to various depths, and from which large and constant supplies of water, which flow over the land in streams, are often procured in districts where this necessary of life is otherwise obtained either of bad quality or in small quantities. Although these wells are intimately connected with geological research, we must, from the want of the necessary space, neglect them,* and notice only those so common in various parts of the world.

a. The observer, neglecting those springs of water which rise from faults, and those which gush out in greater or less abundance from limestone and other

* For an account of Artesian wells, see Penny Cyclopædia.

cavernous rocks, has only to recollect that the more
common springs are produced by the percolation of rain-
water through porous to impervious beds, where they
are stopped, and he will readily be enabled to judge of
the facility or difficulty there may be in procuring water
by means of wells in a given district. Let the annexed
sketch (Fig. 138) represent the section of a hill com-
posed of a porous siliceous sandstone *a*, a clay bed *b*,

Fig. 138.
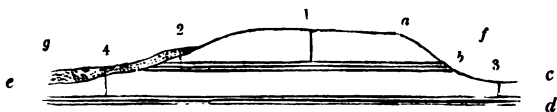
a porous and somewhat calcareous sandstone *c*, and an-
other clay *d*, and the rocks be uncovered by gravel in
the valley *f*, while porous gravel is found in the valley
g. Now, to obtain water by means of wells it would be
necessary to sink through *a* on the top of the hill to
the clay *b*, where the rain-water which has percolated
through *a* will be stopped. This line of water will
probably be shown by a line of springs in the valley *f*;
but the springs which will equally flow from it in the
valley *g* (for the sake of illustration we suppose the
strata horizontal) will be concealed beneath the gravel
e, and will percolate between the clay and it to the po-
rous sandstone *c* on that side. A well therefore formed
at 2, through the gravel, would reach the same line of
water as is obtained at 1, and forms springs in the val-
ley *f*. A well pierced at 3 in the valley *f* would afford
the water stopped by the clay-bed *d*, and the water in
it would probably differ in quality from that obtained

in the line above *b*, because it has traversed a different kind of rock. To reach the same line of water in the valley *g*, it would be necessary to pierce through the gravel *e*, and the sandstone *c ;* and if a thin clay parting should separate *e* from *c*, derived from the bed *b* in that direction, the well 4 would first give the line of water above *b*, and afterwards that above *d*.

b. The observer will readily conceive a variety of circumstances which may modify a supply of well-water in different localities ; but by paying attention to the geological structure of each, so as to obtain a knowledge of the true relative positions of the porous and impervious beds, the influence of faults, if such occur, being duly considered, he will find little difficulty on this head.

c. Care should be taken, when the impervious bed supporting a line of water is thin, not to cut through it ; for by so doing the water will be let out into the rock beneath, if that be porous.

d. Among highly inclined, and even vertical strata, water may sometimes be obtained at different levels, from the saturation of slate or other beds to a certain degree pervious to water at such levels ; so that if a well be formed in such situations, the water will percolate into the cavity and fill it up to the height to which the line of saturation extends. The observer may frequently find little cavities formed in highly inclined or vertical beds of slate in the vicinity of cottages in slate districts, which are filled on this principle.

V. *Mining.*—It is not our intention to enter upon the complicated subject of mining further than to point out the necessity of geological knowledge on the part

of those who seek for metals or coals in districts where
they have not been hitherto found.   The sums of
money thrown away, more particularly in the search for
coal, which this knowledge would have saved, must be
collectively very considerable.   A little black shale, or
piece of lignite, is often sufficient to cause the expendi-
ture of two or three thousand pounds in localities where
there is not the slightest probability of success.   In the
search for metals, matters are frequently not much bet-
ter.   It may be true, and no doubt is so, that particu-
lar metals and coal are not, as was once supposed, con-
fined (viewing the surface of the earth generally) to
rocks formed at particular geological epochs; but it
may be safely stated that, in given areas, both metals
and coal will be found to have given geological po-
sitions.   Thus, for instance, though coal is found in
the oolitic group in Yorkshire, and at Brora in Scot-
land, and anthracite occurs in the grauwacke of Devon,
geologists are perfectly aware that good bituminous
coal, fit to be worked extensively for profitable pur-
poses, does not occur out of the carboniferous group
(see p. 16) in Great Britain.

   It by no means follows that the coal of Australia is
of the same geological age as the coal measures of Eng-
land; indeed, to suppose that all the coal, which may
be profitably worked, is of the same epoch, is to imagine
that, at a given geological epoch, a general entombment
of vegetable matter took place in the rocks then form-
ing over the whole face of the globe,—that this process
continued uninterruptedly for ages,—and that these ve-
getable accumulations only took place then, and were
neither formed before nor after; —a mass of absurdities

which a slight acquaintance with the present state of geology will be sufficient to expose.

a. In the search for coals, observers should be guided by the knowledge of the geological structure of given areas, in whatever part of the world these areas may occur. A knowledge of the general geological structure of eastern Australia will no doubt one day enable the geologists of that country to direct the search for coal in given rocks, and to advise the discontinuance of them in others, precisely as English geologists would advise the search for coal in the proper places, and tell those who seek for it in the numerous other situations where it has been sought, that they were only throwing away time, labour, and money.

b. With regard to metals, a knowledge of the geological structure of given areas is also requisite. As the rocks of the same epoch often change their mineral character in horizontal distances, so also their metalliferous character is found not to be constant throughout extensive areas. A due consideration of this subject would, however, lead us into discussions foreign to the object of this work. It will be sufficient to state, that the knowledge of the geological structure of the British Islands, France, Germany, or any other country, will enable the geological observers in these respective portions of the earth's surface to state, that given rocks, or given modes of their occurrence, may afford useful metals, while in other rocks or situations the search for them can scarcely be otherwise than fruitless. In England, for instance, no one would expect to discover valuable tin and copper mines in the cretaceous or oolitic groups; while the search for these metals in

Cornwall, at the junction of granite and the slate rocks, would be highly proper.

c. We may here notice the singular circumstance, that in this country, where so much capital is invested in metalliferous mines and collieries, there should be no national school or college of mines, though the great utility of such establishments is amply proved by experience in foreign countries, where for the most part the capital thus invested is comparatively trifling. British miners and coal-workers are compelled to pick up their information how they can. If by good fortune young men are placed under those who value science, and are aware of the advantages which may be derived from it, they have certainly little reason to complain; but, unfortunately, this is not the lot of the many. A College of Mines, properly conducted, would be alike beneficial to those who invest their money in mines and collieries, and those who work them. It could, indeed, scarcely be otherwise than a national benefit. Hitherto, however, the attempts which have been made to call the attention of government to this subject have been unsuccessful.

VI. *Building.*—Disregarding private dwellings, on which such various materials are employed, according to the motives that lead to their erection, it may be fairly stated, that a knowledge of the general structure of rocks, and the situations whence the best materials may be obtained, is essential to those who are either charged with or direct public works. A stone which may be sufficiently durable if plunged beneath water, may not be so when kept alternately wet and dry by the rise and fall of water in a river or on a tidal coast, or when

wholly exposed to the action of the atmosphere. A
somewhat porous sandstone, for instance, may do well
when kept constantly under water; but the same rock
when exposed to the atmosphere, more particularly in
climates subject to frost, might gradually crumble away
from causes previously noticed (p. 35).

a. The observer desirous of selecting a stone to be
exposed to atmospheric influences would do well to
study the mode in which it is weathered in the locality
whence it is obtained. He may there learn which part,
if it be a compound rock, is liable to give way before
such influences, and the conditions under which it
does so. Granite generally is considered a proper mate-
rial for national monuments. Some granites, however,
though they may be hard and difficult to work when
first taken from a quarry, are among the worst building
materials, in consequence of the facility with which the
felspar in them decomposes when exposed to the action
of a wet atmosphere, in a climate which may be warm
during part of the year, and cold during the other.
Rocks which contain compact felspar are often very
durable. Some of the *elvans*, as they are provincially
termed, of Cornwall, seem to be particularly durable
when exposed to atmospheric influences ; for some of
the old and external carved stone-work of the churches
constructed with this material in that part of England
is as perfect as when first put up.

Rocks which readily absorb moisture, such as many
of those which are termed freestones, are exceedingly
bad for the external portions of exposed public build-
ings ; since, in countries where frosts occur, the freez-
ing of the water in the wet surface continually peels off

the latter, and eventually destroys the ornamental work carved upon it. It should be recollected that free-stones, so termed because they are easily worked, are often valued because they may be cut readily when first taken from the quarry, and subsequently become harder when exposed to the atmosphere; and that this quality arises from the evaporation of the water contained in the stone when forming part of the natural rock. Now, some of these freestones again readily absorb moisture, while others do not: hence the latter should be pre-ferred; and an observer should ascertain this fact by experiment before any given freestone is selected.

Some freestones are formed of particles of sand cemented together by different substances, the cement-ing matter being sometimes siliceous, at others calca-reous, and at others again formed of oxide of iron. In the first case, the freestone would not suffer from the chemical action of atmospheric influences upon it; while in the second, rain-water containing carbonic acid would tend to dissolve the calcareous matter, and de-prive the sand of its cement; and in the third, the action of atmospheric influences would tend to render the material unsightly by staining it with iron rust.

The little attention that has been paid in the erec-tion of national monuments in this country to the du-rability of the materials of which they are constructed, is well known. There is no want of good materials, if they would be sought out; and it often occurs to the geologist to find them. A more beautiful stone for public works can nowhere be obtained than from a mass of white granite near Okehampton in Devonshire. Judging from the weathered character of this rock, it

must be extremely durable. It is composed of white felspar, quartz and mica, and looks as white as statuary marble. Hitherto, we believe, this beautiful material has only been formed into one or two chimneypieces.

b. In selecting stone for artificial harbours, break-waters, quays, and bridges, the observer should note those kinds which best suit the different parts of the work to be executed. Where a pier or breakwater has to resist the action of heavy breakers, charged with the pebbles of a beach, a harder material becomes necessary than when it has only to encounter the action of breakers not so charged. In both cases the weight of a stone is an important consideration, since the greater the weight in the same bulk, the greater the resistance to removal from the blow of a breaker, other things being equal. An observer, therefore, should ascertain the specific gravity of a stone he may be desirous of employing. Several kinds of stone, otherwise equally good, may vary much in this respect; so that a pier of given dimensions may differ considerably from another in weight according to the material employed.

In constructing piers, quays, and bridges, where the water-level varies, materials which may be good for one part of the work may not be so for other portions. Many rocks which may be advantageously employed in situations constantly under water, will be found liable to decomposition when exposed to the atmosphere, particularly in those portions kept alternately wet and dry by the rise and fall of tides, or other causes producing changes in the level of the water. An observer may often obtain information on this head by studying the condition of rocks on the banks of rivers and on the sea-

shore, and geologists are thus frequently aware of many situations where quarries for the purposes above mentioned may be advantageously opened.

It may here, perhaps, not be altogether out of place to notice the benefit that might arise if there were some National Museum for the purpose of showing the application of Geology to the useful purposes of life, or, in other words, the mineral wealth of the country. One in which the various mineral substances used for roads, in constructing public works or buildings, employed for ornamental purposes, or from which useful metals are extracted, should be arranged with every reference to instruction, and the situations whence they were obtained carefully marked on good maps, such as those of the Ordnance. In this manner a large amount of information, which is now scattered, might be condensed, and those interested be enabled to judge how far our known mineral wealth may be rendered available for any undertaking they are required to direct, or may be anxious to promote, for the ornament or good of their country.

THE END.

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